Sponsored by RF & Optical Systems, Systems Design,
and The Ed Wells Initiative

Commercial Satellite Communication Applications

Course No. 9SV109

Student Guide
Volume I

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The Textbook & Student Guides for this course are provided to qualified attending employees compliments of...

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Module 8 - Systems Descriptions of Boeing Commercial Satellite Projects *8-0*

Course Agenda

Day 1

- **Introduction**
- ***Module 1 - Overview of Boeing Commercial Satellite Projects***
- **Module 2 - Satellite Technology**
- **Lunch**
- **Module 3 - Satellite Links and Access Methods**
- **Module 4 - Frequency Coordination and Regulation**

Day 2

- **Module 5 - Direct-to-Home Television Services**
- **Module 6 - Telephone Services**
- **Lunch**
- **Module 7 - Data/Multimedia Services**
- ***Module 8 - Systems Descriptions of Boeing Commercial Satellite Projects***
- **Course Evaluation**

Day 1 Agenda

8:00	**Introduction**
8:10	**Module 1: Overview of Boeing Commercial Satellite Projects**
9:00	**Module 2: Satellite Technology**
	Module 2A: Orbits
9:30	**Module 2B: Bus Subsystems**
10:00	*Break*
10:15	**Module 2C: Communication Subsystem**
11:00	**Module 2D: Tracking, Telemetry, and Command**
11:30	*Lunch*
12:15	**Module 3: Communications 101**
2:30	*Break*
2:45	**Module 4: Frequency Coordination and Regulations**
4:30	*End of Day*

Day 2 Agenda

8:00	**Module 5: Direct-to-Home Television Services by Satellite**
9:45	*Break*
10:00	**Module 6: Telephone Service**
11:15	**Module 7: Data/Multimedia Services**
11:45	*Lunch*
12:30	**Module 7: Data/Multimedia Services (cont)**
1:15	**Module 8: Boeing Commercial Satellite Projects--System Descriptions**
	Module 8A: Teledesic
2:00	**Module 8B: Global Broadcast Service**
2:30	**Module 8C: Resource 21**
3:00	*Break*
3:15	**Module 8D: DigitalXpress**
3:45	**Module 8E: Aviation Information Services**
4:15	**Course Evaluation**
4:30	*End of Day*

Web Page - Course Description

http://plato.ds.boeing.com/training/CSatDesc.htm

This course provides a broad overview of how satellites are used to provide communications; it is intended for both engineers and managers with a wide range of experience levels. Students learn terminology & technology of satellite communications, including:

1) communication satellite system architectures,
2) satellite constellations,
3) communication satellite payloads and other subsystems,
4) the regulatory environment/ governmental license process and allocation of frequency bands around the world,
5) direct broadcast satellite (DBS) service and technologies, and
6) satellite links and access methods.

The technical discussion includes applications for specific products and services. The course includes a review of the major satellite communications projects within Boeing Information, Space, & Defense Systems.

Course Objectives

Upon completion, students should be able to:

- **Describe satellite communications fundamentals to the growing number of employees working on projects related to satellite communications.**
- **Explain the differences between communications satellite system architectures, satellite constellations, satellite bus and payload designs, and multiple access and modulation techniques.**
- **Explain the regulatory process and applications of satellite communications**

Course Development & Review Team

http://plato.ds.boeing.com/training/CSatTm.htm

Bob Higgins
Bill Richards
Jeff Krinsky

Steve Cuspard
Ed Gentzler
Bill Milne
Bob Perovich
Jim McClelland

1st Instructor Introduction

http://plato.ds.boeing.com/CSatTms.htm

Bill Richards   3E-80   253 / 773-8849

william.r.richards@boeing.com

Background / Qualifications for teaching course:

- **Senior Principal Engineer, DigitalXpress & Aviation Information Services Systems Team**
- **Systems Engineer Manager Ku-band Systems, Hughes Communciations Incorporated**
- **10 years Systems Engineering on commercial communications satellites at Hughes**

2nd Instructor Introduction

http://plato.ds.boeing.com/CSatTms.htm

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robert.p.higgins@boeing.com

Background / Qualifications for teaching course:

- **Senior Principal Engineer, worked early on Teledesic, currently working on AIS**
- **Communication system design for LPI Radio**
- **Initial SATCOM work on R-21**
- **Initial Phase II concept work on GBS**

Additional Resources

COURSES:

- **Course #9SV608 “Satellite Communications” (Off-Hr.), 30 hrs. For course description, see-- http://natasha.ca.boeing.com/courses/0/8/9SV608.html**
- **Course #9SV1001 “Coding Theory” (Off-Hr.), 30 hrs. For course description, see-- http://natasha.ca.boeing.com/courses/0/1/9SV1001.html**
- **George Washington University continuing engineering education courses in satellite communication. http://www.gwu.edu/~ceep/g-documents/comm2.htm**
- **Applied Technology Institute courses on satellites and communications. http://catalog.com/hitekweb**

Additional Resources

- **UCLA Extension courses.**
  http://www.ucla.edu/home/continuing.html

BOOKS: Communications

- **Morgan and Gordon, *Communications Satellite Handbook*, Wiley, 1989**
- **Bernard Sklar, *Digital Communications, Fundamentals and Applications*, Prentice Hall, 1988**
- **John G. Proakis, *Digital Communications*, 2nd edition McGraw-Hill, 1983**
- **J.C. Bic, et.al., *Elements of Digital Communications*, Wiley, 1991**

Additional Resources

- Roger Freeman, *Reference Manual for Telecommunications Engineering*, Wiley, 1985

Coding Theory

- Michelson and Levesque, *Error-Control Techniques for Digital Communications*, Wiley, 1985
- Lin and Costello, *Error Control Coding: Fundamentals and Applications*, Prentice-Hall, 1983
- Peterson, Weldon, *Error-Correcting Codes*, MIT Press, 1972

Antennas

- Constantine Balanis, *Antenna Theory, Analysis and Design*, Wiley, 1982

Additional Resources

Computer Networks

- Andrew Tanenbaum, *Computer Networks*, Prentice-Hall,

Data Compression

- Jayant & Noll, *Digital Coding of Waveforms, Principles and Applications to Speech and Video*, Prentice-Hall, 1984
- Bhaskaran & Konstantinides, *Image & Video Compression Standards, Algorithms and Architectures*, 2nd edition, Kluwer Academic, 1997

Propagation

- Brussaard and Watson, *Atmospheric Modeling and Millimetre Wave Propagation*, Chapman and Hall,

Additional Resources

- **Warren Flock, *Propagation Effects on Satellite Systems at Frequencies Below 10 GHz*, NASA Reference Publication 1108 (02), 1987**

Space Systems

- **TRW Space Data, TRW**
- **Larson & Wertz, *Space Mission Analysis and Design*, Kluwer Academic, 1992**
- **Bate, Mueller, & White, *Fundamentals of Astrodynamics***
- **Piscane & Moore, *Fundamentals of Space Systems*, 1994**

Sign the Roster

Record your attendance on the roster:

- **Initial the roster (to the left of your name)**
- **Record the # of hours you will attend today:**

  > ***If you will attend ALL of today's class,***
  > ***put "8" (for 8 hrs.) in today's box, at far right.***
  > **(1st box is for 1st day; 2nd box is for 2nd day)**

  > ***If you will attend only PART of today's class,***
  > ***record the actual number of hours you attend***
  > ***(in today's box, at far right).***

Complete a Course Evaluation

Answer these 4 questions on back of form:

12. What *did you get* from the course *that was good*?

13. What *didn't you get that you expected* from the course?

14. What would you *like to have in-hand* when you leave?

15. What *changes/improvements* would you like to see?

Hand in your Evaluation as you leave.

Instructor introduction

Jeff Krinsky 8H-01 (206)544-2703

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Background / Qualifications for teaching course

- Principal Engineer, DigitalXpress, Boeing
- 10 years fiber optics in adverse environments, Boeing
- Systems Engineer for AJ LPI Frequency Hop Spread Spectrum communications, Harris
- Project Engineer, Space Shuttle Project, MMC
- Electronics Engineer Telephonics

Course Agenda

- Day 1
    - Introduction
    - Module 1- Overview of Boeing Commercial Satellite Projects
    - Module 2 - Satellite Technology
- Day 2
    - Module 2 - Satellite Technology conclusion
    - Module 3 - Communications 101

Course Agenda

- Day 3
  - Module 4 - Frequency Coordination and Regulation
  - Module 5 - Direct to home television services
- Day 4
  - Module 5 - Direct to home television services Concl.
  - Module 6 Telephone Services
- Day 5
  - Module 7 Data Multimedia Services
  - Module 8 Systems Descriptions of Boeing Sat. Com. Projects

Reading Assignment

Reading Assignment

Week	Chapter
1	1,2,3
2	4,5
3	6,7
4	8,9
5	10,11

Work Groups

- Please form groups of about 4 to 5 people.
- Introduce yourselves.
- Exchange contact information
  - Name
  - e-mail address
  - phone number
- Please E-mail me! :-) Questions, comments, suggestions, & what do you want from the course, etc. How can I help?

Course 9SV109

- Class No. 18877, 18954-7
- 4:30 - 7:45 PM PST
- 2 proposed 15 min breaks
  - 4:30 - 4:45
  - 5:45 - 6:00
  - Are the proposed breaks to long?

Satellite Subsystems

- Communications
- Antenna
- Spacecraft bus

Communications Subsystem

- Receivers
- Multiplexes
- High power amplifiers
- Switching
- Digital subsystem

Antenna subsystem

- Reflector
- Feed
- Feed network

Bus Subsystems

(per course outline)

- Power
- Command and Data handling
- Attitude control
- Structure/mechanical
- Thermal

Bus Subsystems

(per: The Satellite Communications handbook
Sec. 3.1. Issues in Satellite System Management)

- Tracking, telemetry, and command
- Solar panel
- Batteries
- Reaction control and propulsion
- Spacecraft control processing
- Attitude control
- Thermal control
- Structure

Satellite Subsystems
(Per Hughes)

- Propulsion
- Power
- Communications
- Thermal control
- Attitude control
- Operators & ground control

Bus Subsystem - Power

- Function: Provide electrical power for the the Satellite payload
- Main elements
    - primary energy source (e.g., photovoltaic cells)
    - secondary energy source (e.g., batteries)
    - power control & distribution

Bus Subsystem - Power

- Show the 3 Figs. on P. 314 & 315
  - evolution of mission power demand
  - power outputs: mission duration relationship between energy source and appropriate scenario
  - schematic of typical spacecraft power system block elements

Bus Subsystem - Power

primary energy source

- Converts a fuel (i.e., chemical energy or nuclear energy) or electromagnetic energy (e.g., light or microwave) in to electrical power.
- Majority or present day communications spacecraft use a solar array as the primary energy source.
- On manned missions, fuel cells have been the most frequently used primary power source.

Bus Subsystem - Power

secondary energy source

- Stores energy which is subsequently delivered to the satellite system and payload when the primary systems energy is not available
- The most usual situation occurs during an eclipse when the primary system is a solar array. Eclipse duration depends on the spacecraft orbit (e.g., Geo ≈ 1.2 h/ 24 h).

Bus Subsystem - Power

secondary energy source

- For short times batteries have the highest efficiency
- For high power (e.g., >100 kW) a solar array / regenerative fuel-cell combination can have advantages.
- See Figs.

Bus Subsystem - Telemetry, Command and Data And data Handling

- Provides two way flow of information between a spacecraft and its ground station(s)
  - transmission (downlink from the satellite)
    - health of the subsystems
    - payload data if it is a scientific or observational mission
  - receiving (uplink from the ground station(s))
    - enables changes to role of the spacecraft
      - correct faults
      - reorientation
      - operate mechanisms

Bus Subsystem - Telemetry, Command and Data And data Handling

- Ranging transponder
    - is part of the system by which the ground controller tracks the spacecraft and determines its orbit.

Bus Subsystem - Telemetry, Command and Data And data Handling

- Telemetry Data
  - temperatures
  - pressures
  - voltages and currents of power supplies
  - operating status of equipment (single bit)
  - redundancy status
  - deployment of mechanisms
  - attitude data
  - payload data

Bus Subsystem - Telemetry, Command and Data And data Handling

- several hundred to about 1k parameters are monitored on a modern communications satellite
- Typical monitoring requirement of a communications payload includes:
  - temperatures of TWTs and other repeater equipment
  - power supply voltages and currents
  - operating and redundancy status monitors for the many waveguide switches in the RF ‘plumbing’
  - analog power monitors at each main RF equip. interface
  - telemetry monitoring of digital gain settings telecommanded to the various channel amplifiers

Bus Subsystem - Attitude Control

- Purpose: Correctly orient the main structure of the spacecraft to the required accuracy
- Correct Attitude is determined by the mission
  - frequently related to an earth-based frame of reference (e.g., one face of the spacecraft must point down the local vertical)

Bus Subsystem - Attitude Control

- Can be considered as a momentum management system
    - angular momentum is a commodity that can be acquired, disposed of or stored.
- Must know the time-history for the spacecraft's required rotational motion and angular velocity.

Bus Subsystem - Attitude Control

- For a circular orbit local vertical will rotate at a constant rate = 1 rev/orbit about the normal to the orbit plane. If one face of a structure with no momentum bias is required to point down the vertical then no torque is needed to maintain this condition provided that a principal axis is aligned with the normal to the orbit plane. If the normal is not a principal axis then a cyclic torque is needed.

Bus Subsystem - Attitude Control

- For an elliptical orbit a local vertical will not have a constant angular velocity. If one face of the structure is required to point down the vertical and a principal axis is aligned with the normal to the plane, then no torque is needed to maintain the mean angular rate, constant angular momentum. But torque will be needed to produce the fluctuations in momentum about the mean values.

Bus Subsystem - Attitude Control

- If the structure is not rotating, frequently the cause for astronomical missions, then no torque is needed to maintain this condition once it has been achieved. This will be approximately true of solar arrays too, since their angular velocity is likely to be virtually zero as they point towards the sun, even if the main structure is rotating.

Bus Subsystem - Attitude Control

- Torque requirements
- Momentum storage
- Momentum bias
- Show block diagram Fig P.285

Bus Subsystem - Attitude Control

Internal Torques

- Mechanisms
- Fuel movement
- Astronaut movement
- Flexible appendages
- General mass movement

Bus Subsystem - Attitude Control

External Torques

Source	**Height range over which it is potentially dominant**
• Aerodynamic	(< about 500 km)
• Magnetic	(500-35,000 km)
• Gravity gradient	(500-35,000 km)
• Solar radiation	(> synchronous)
• Thrust misalignment	(all heights)

Bus Subsystem - Attitude Control

- Structure - Spinning or not
- May or may not use momentum bias or momentum storage
- May use a variety of torqueing methods

Bus Subsystem - Attitude Control

- Thrusters (external). Uses fuel, can control momentum build-up
  - gas jets
  - magnetic
  - gravity gradient
  - Solar radiation

Bus Subsystem - Attitude Control

- Thrusters (internal). No fuel required, cannot control momentum build-up
  - Reaction wheels (RW)
  - momentum wheels
  - Control moment gyroscope (CMG)

Bus Subsystem - Attitude Control

- Attitude measurement
  - Right-handed coordinate system usually used
  - Choose datum axes & spacecraft axes
  - Use Euler angles, direction cosines, quaternions, etc.
  - Three pieces of information are needed
    - Angles of yaw, pitch and role as measure of rotations about the z-, y-, and x- axes respectively.

Bus Subsystem - Attitude Control

- Types of sensors
  - reference sensor: gives a definite fix by measuring the direction to an object such as the sun or a star etc.
  - Inertial sensors: measure continuously, but they measure only changes in attitude, effectively relative to a gyroscope rotor. They need a fix or calibration form reference sensors. In between fixes their errors progressively increase due to random drifts.

Bus Subsystem - Attitude Control

Types of Reference sensors

- Sun Sensors
- Earth Sensors
- Star Sensors (most accurate sensor in common use)
    - star scanners
    - star trackers
    - star mappers
- Radio frequency beacons
- Magnetometers

Bus Subsystem - Attitude Control

Types of Reference sensors

- Gyroscopes
  - mechanical
  - optical
    - ring laser gyroscope (RLG)
    - fiber optic gyros (FOG)

Bus Subsystem - Spacecraft Structures

- Principal goals
  - minimize mass
  - maximize reliability

Bus Subsystem - Spacecraft Structures

- Constraints
  - must survive testing and launch
  - must operate in zero-gravity
  - stiffness
  - accommodation for the payload and spacecraft subsystems (e.g., subsystems: thermal design, attitude control, communications, and power)
  - provision for environmental protection
  - thermal and electrical paths
  - accessibility

Bus Subsystem - Thermal

- Thermal Control: maintains structural and equipment integrity over the long periods of time.
- If the satellite and payload could operate reliably at any temperature thermal control would not be required
- Design: identifies sources of internal and external heat and designing the paths for transporting and rejecting heat such that all components remain within required temperature limits.

Bus Subsystem -Thermal
Environment

- Assuming earth orbiting
  - > 300 km aerodynamic heating is negligible
  - Heat transfer is by radiation and the actual temperature of the spacecraft is determined by the exchange of energy by means of the following:
    - direct solar radiation
    - solar radiation reflected from nearby planets (albedo radiation)
    - thermal energy radiated from nearby planets
    - radiation to deep space from the spacecraft

Bus Subsystem - Thermal

Design

- Passive thermal control
    - solar reflectors & absorbers
    - flat reflectors and absorbers
    - fluid loops
    - super insulation
    - heat pipes

Bus Subsystem - Thermal Design

- Active Thermal control systems
  - Variable external radiation devices
    - bimetallic fins
    - gas-bellows- actuated
  - Thermostatically controlled heaters
  - Thermoelectric cooling
  - Fluid transport systems

Bus Subsystem - Thermal design

- Concrete example P. 361

Communications systems performance terms

- **Link** is the name given to the communication transmission path from the modulator and transmitter through the channel and up to and including the receiver.
- The **Channel** is the name given to the propagating medium between the transmitter and receiver.
- A **Link Description** quantifies the average signal power that is received, the available bandwidth, the noise statistics, and other impairments such as fading

Communications systems performance terms

- **Free space** assumes a channel region free of all objects that might affect radio frequency propagation by absorption, reflection, or refraction. It also assumes that the atmosphere in the channel is perfectly uniform and nonabsorbing, and the earth is infinitely far away or its reflection coefficient is negligible. RF energy arriving at the receiver is assumed to be a function of the distance from the transmitter (following the inverse square law).

Definitions

- $\mathbf{P_t}$ = radio transmitter average output power [W]
- $\mathbf{G_t}$ = gain of transmitting antenna [dB]
- $\mathbf{G_r}$ = gain of the receiving antenna [dB]
- **EIRP** = Effective Isotropic Radiated Power [W]
- **EIRP** = $\mathbf{P_t\,G_t}$ [W]

Definitions

- $\mathbf{S}$ = Predetection average signal power arriving at the output of the receiver antenna [W]
- $\mathbf{S}$ = EIRP G_r / $(L_s L_o)$
  - $\mathbf{L_s}$ = Space Loss
  - $\mathbf{L_o}$ = Other Losses
- $\mathbf{L_s}$ = $(4 \Pi d / \lambda)^2$ = path loss
  - **d** = distance between the transmitter and receiver
  - λ = wavelength

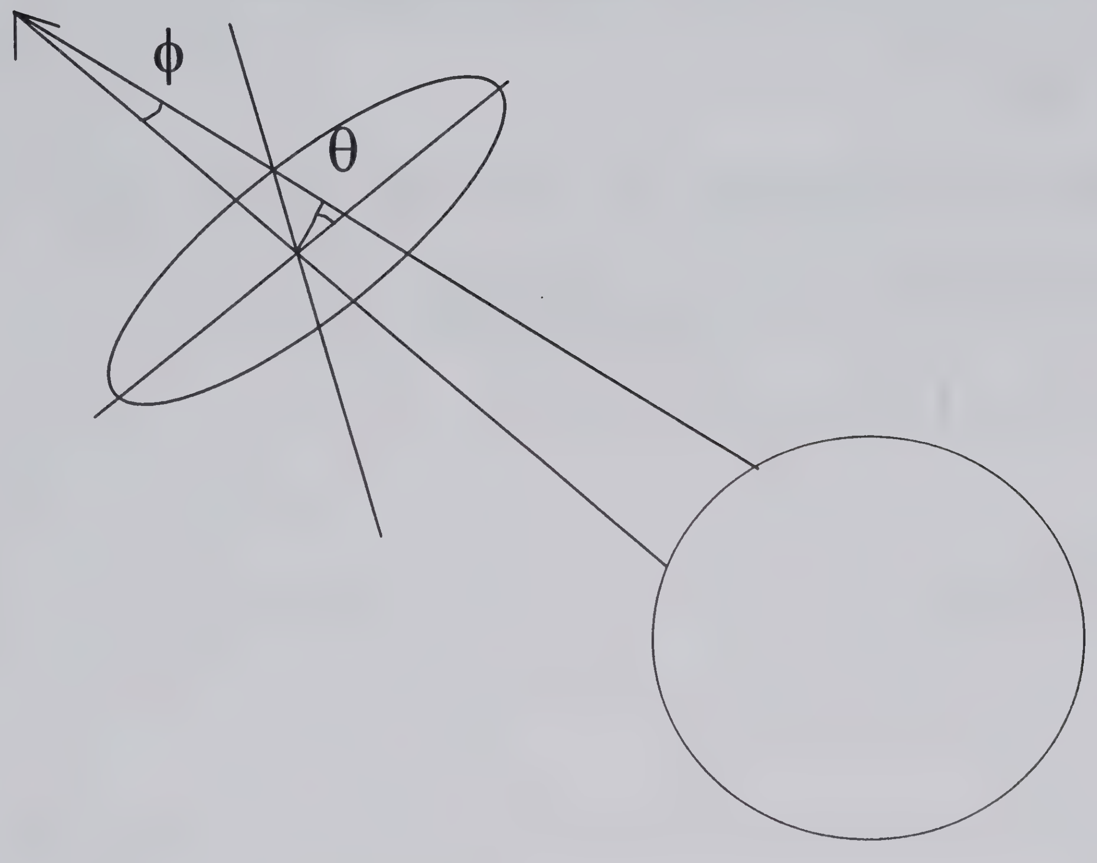
Noise

- Assume additive white Gaussian noise (AWGN)
- **N** = noise ≅ k T W
  - **k** = Boltzmann’s constant = 1.38 E-23 joule / K
  - **K** = effective temperature in Kelvin
  - **W** = bandwidth in Hertz

Noise-power spectral density

- $\mathbf{N_0}$ = noise power spectral density
- $\mathbf{N_0}$ $= N / W = k\,T$
- $\mathbf{S / N_0}$ $= (\mathrm{EIRP}\,G_r/T) / (k\,L_s\,L_o)$
- $\mathbf{E_b / N_0} = S\,T_b / N_0 = S / N_0\,(1/R)$

Radiated Power = F (θ,φ)



Noise

- **AWGN** = Additive White Gaussian Noise
- Noise ≈ k T W
- k = Boltzmann's constant (1.38 E-23 joule / K)
- T = effective temperature in Kelvin
- W = bandwidth [Hz]

Commercial Satellite Communication Applications
Course No. 9SV109

Module 2A
Orbits

October 24, 1997

Boeing Information, Space, & Defense Systems

Module Objectives / Assessments

2A- 2

What you can learn in this module:

- **What are the advantages and disadvantages of several types of orbits**

How to measure your success:

- **Can you describe three different orbit configurations and what is the primary advantage of each orbit**

Satellite Orbits
Effects on Communications

Visibility

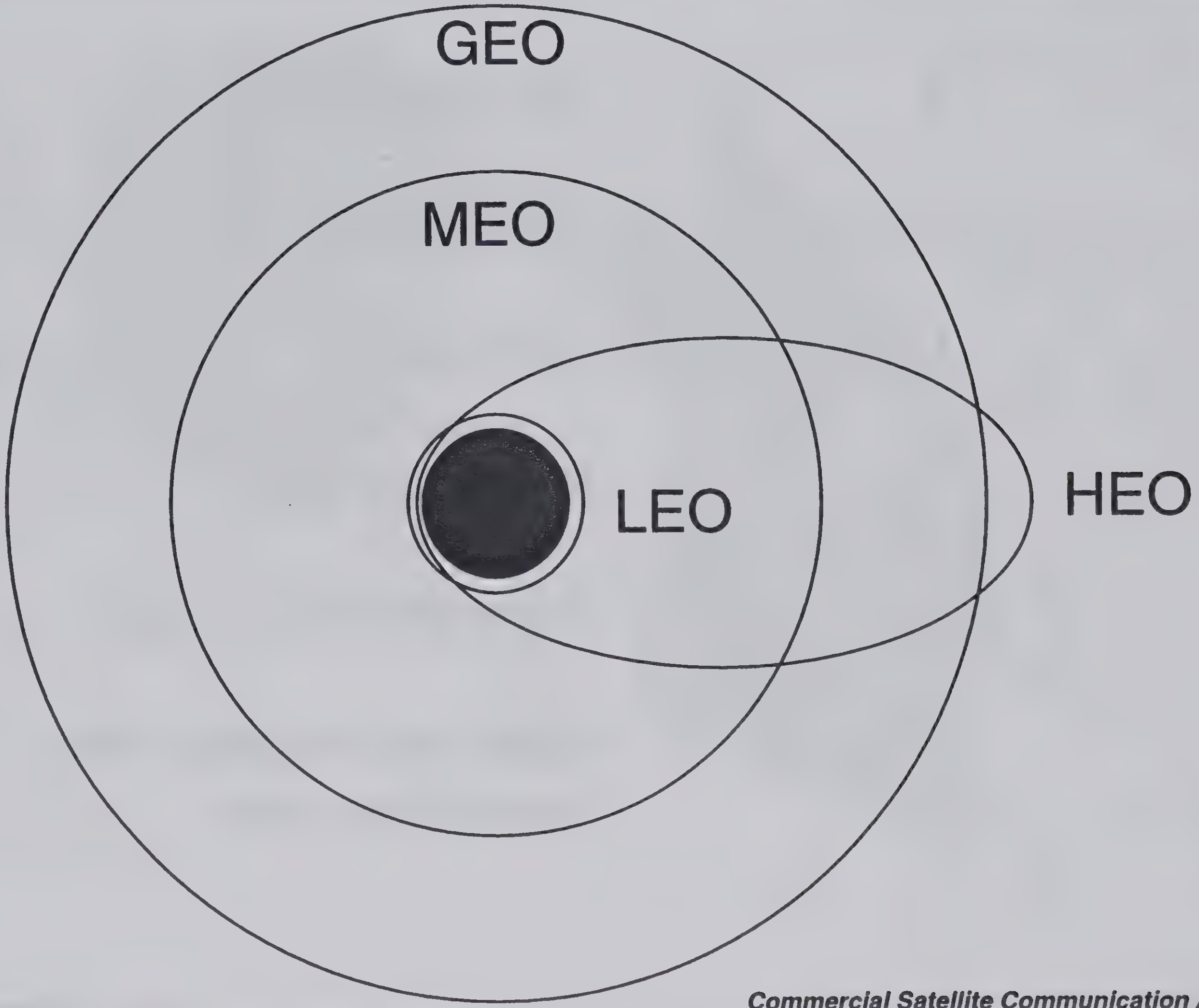
Antenna Tracking/pointing

Range (delay)

Range-rate (Doppler)

Operational outages

Orbits

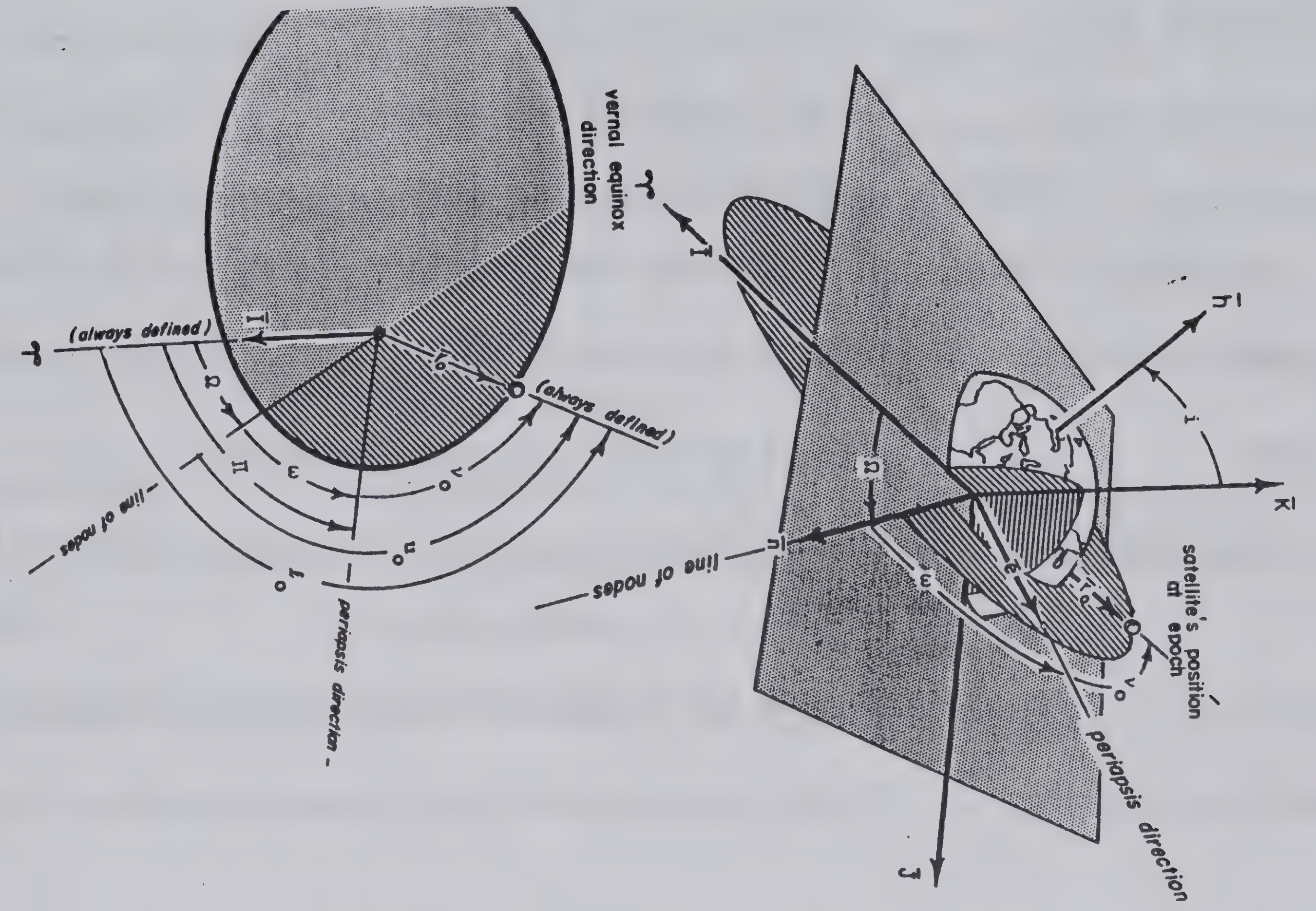


Orbit Elements

a	**Semimajor axis**
e	**Eccentricty**
i	**Inclination**
M	**Mean anomaly**
ω	**Argument of perigee**
Ω	**Right ascension of the ascending node**

Orbit Elements (cont)

2A- 6



Definition of Terms

Semi-major axis:	**Long axis of ellipse**
Semi-minor axis:	**Short axis of ellipse**
Eccentricity:	**Distance from ellipse center to foci divided by semi-major axis**
Apogee:	**Point of orbit furthest away from earth**
Perigee:	**Point of orbit closest to earth**
Line of apsides:	**Line joining apogee through center of earth**
Inclination:	**Angle of orbit with respect to equator**
Ascending node:	**Point where orbit crosses equator S to N**

Definition of Terms (cont)

Descending node:	**Point where orbit crosses equator N to S**
Line of nodes:	**Line joining ascending and descending nodes through center of earth**
Argument of perigee:	**Angle from ascending node to perigee**
RAAN:	**Angle from vernal equinox direction to line of nodes**
Mean anomaly:	**Angle from perigee to satellite position assuming average rotation rate**
Prograde:	**Inclination of 0 to 90 degrees**
Retrograde:	**Inclination of 90 to 180 degrees**

GEO Orbit Parameters

Circular orbit

Altitude - 35,872 km

Inclination - 0 degrees

Orbit period - 1 day

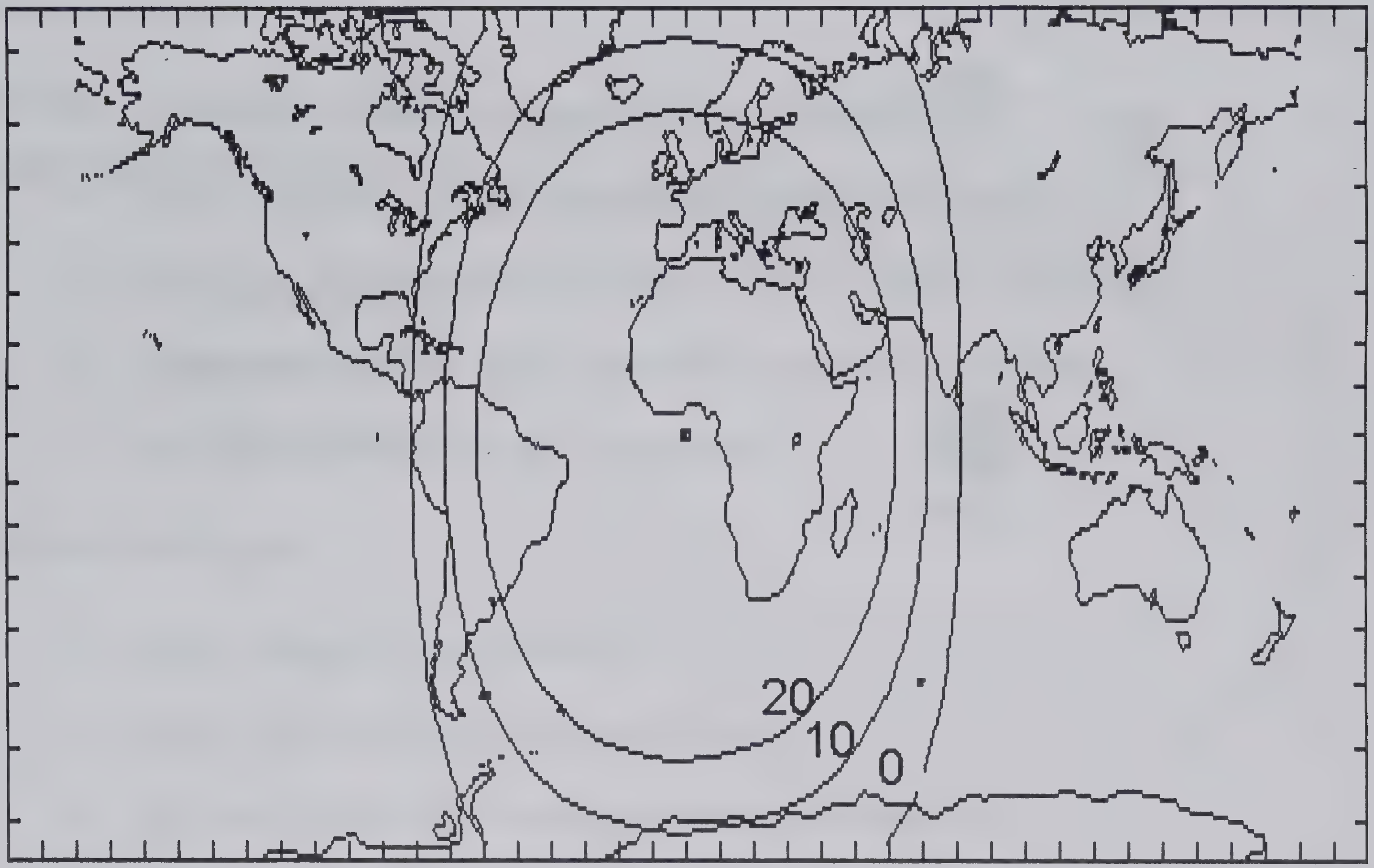
Visibility period - continuous

Maximum range 40,470 km (10° elevation)

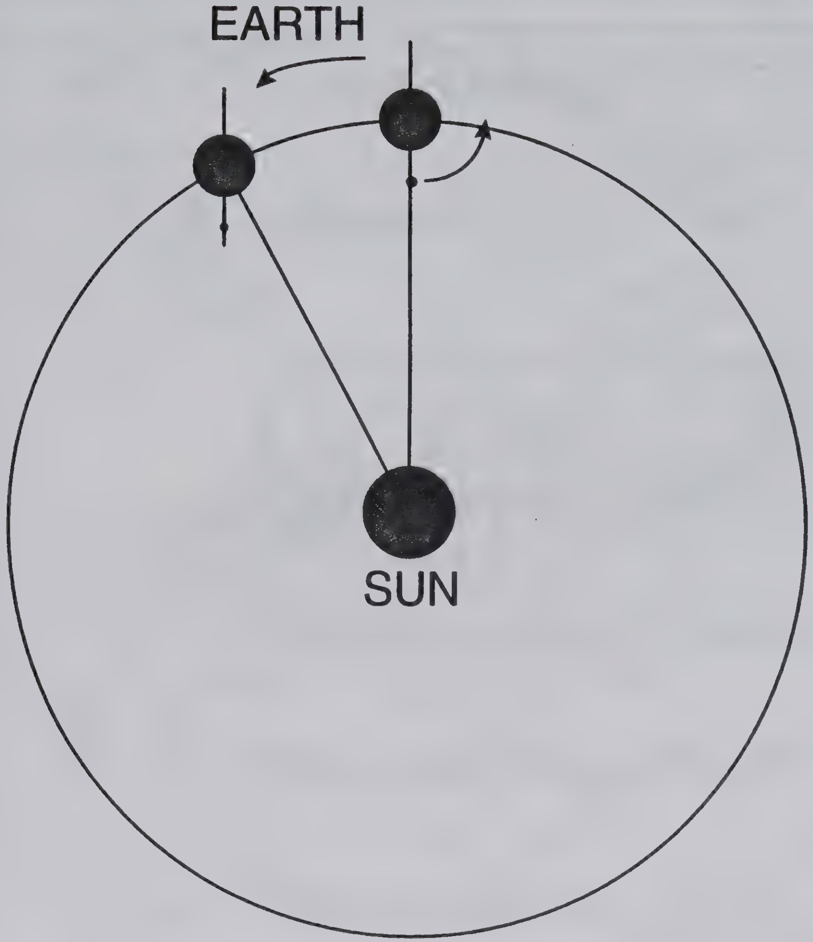
Round trip time delay - 271 ms

GEO Visibility

2A- 10



Sidereal Day



360° circuit of earth
in one sidereal day

23 hours
56 minutes
4 seconds

GEO Advantages/Disadvantages

2A- 12

Advantages

- Stationary with respect to earth station
- Earth station antennas don’t have to track
- Single satellite can cover 38 % of earth surface
- Three satellites can provide global coverage
- No satellite hand-off required

Disadvantages

- Long range (time delay)
- High latitudes not covered well
- Limited orbit slot assignments available
- Solar outages

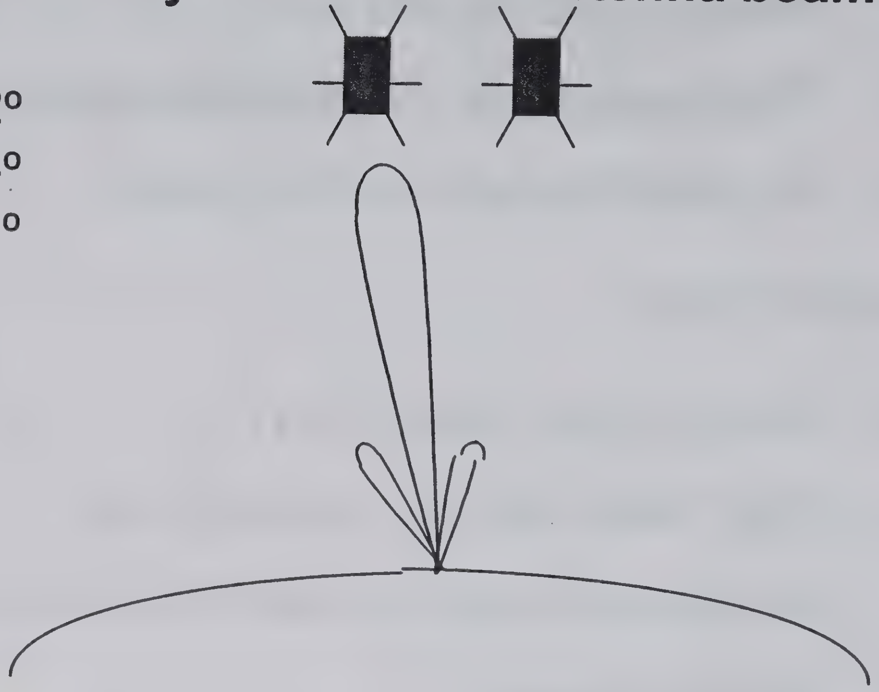
Limits on Orbital Slots

Requirement is non-interference

Don't want one earth station talking to two satellites

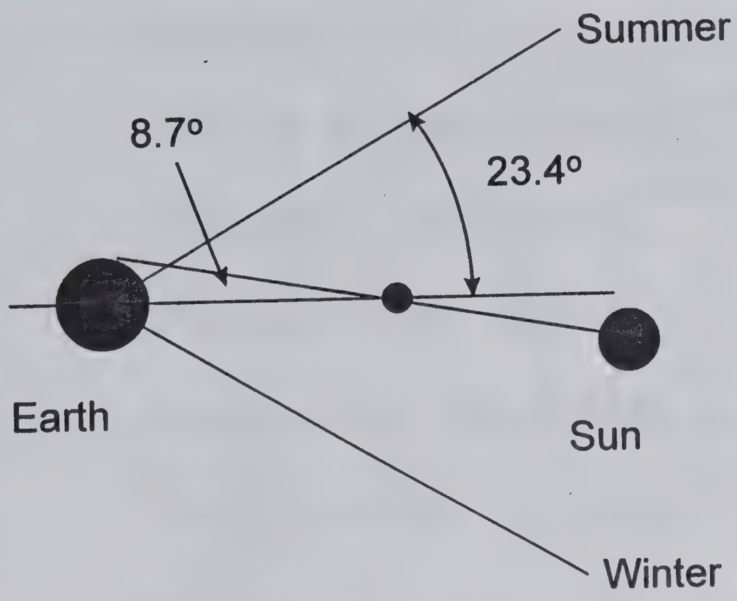
Spatial separation required by earth station antenna beamwidth

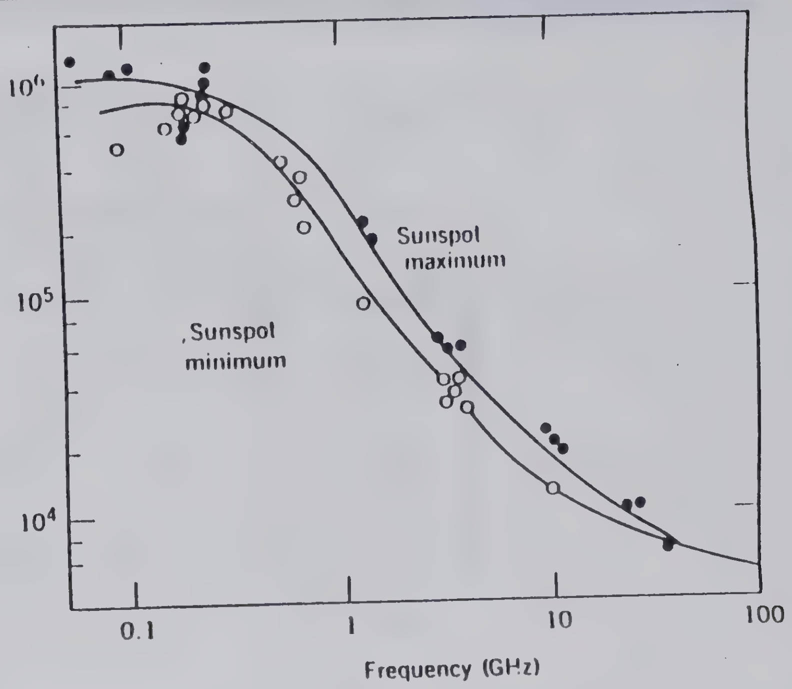
U. S. policy	2°
Japan policy	4°
Europe policy	3°



Sun Outage

2A- 14





Sun in direct line from earth station to satellite

High effective noise temperature

Decreases SNR of downlink

Eclipse Periods

2A- 15

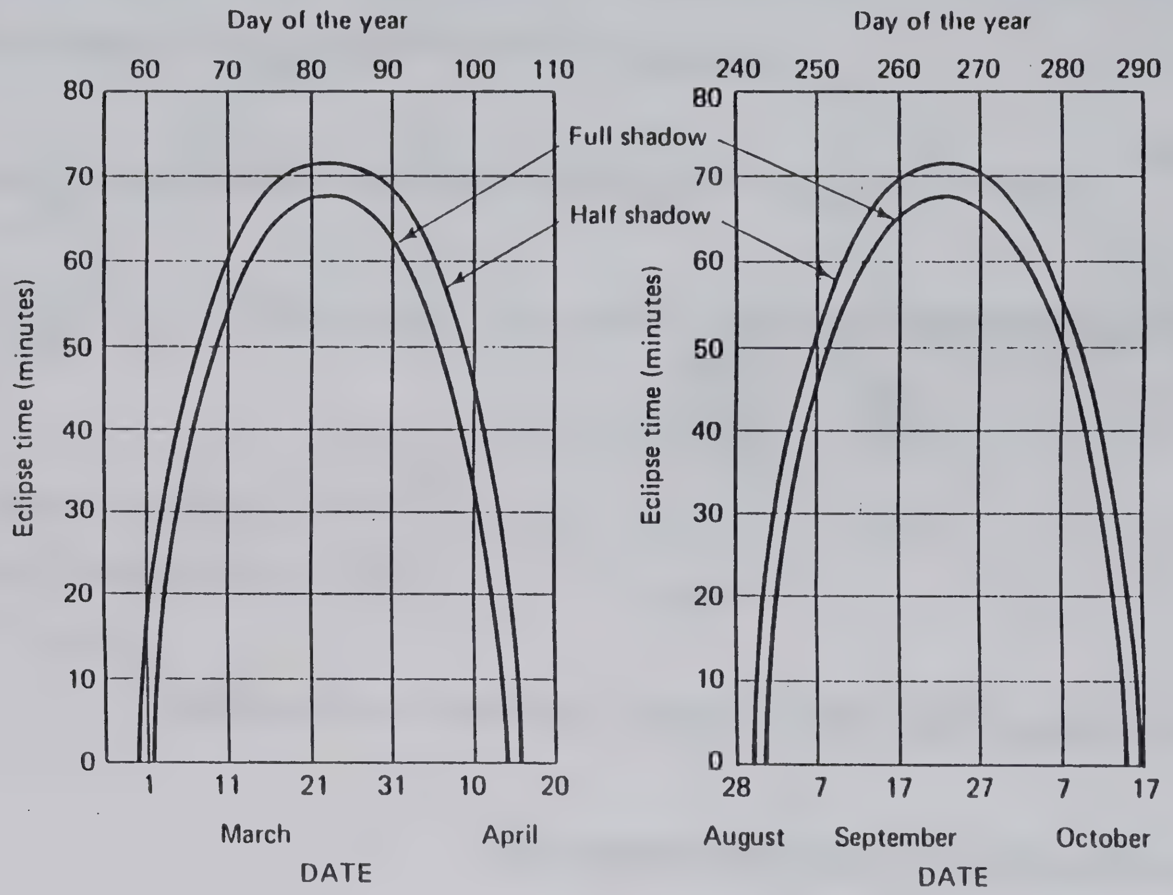


Figure 2.14 The dates and durations of satellite eclipses.

HEO Orbit Parameters

2A- 16

Molniya orbit

Highly eccentric orbit

Apogee - 39,200 km

Perigee - 500 km

Inclination - 65.4 degrees

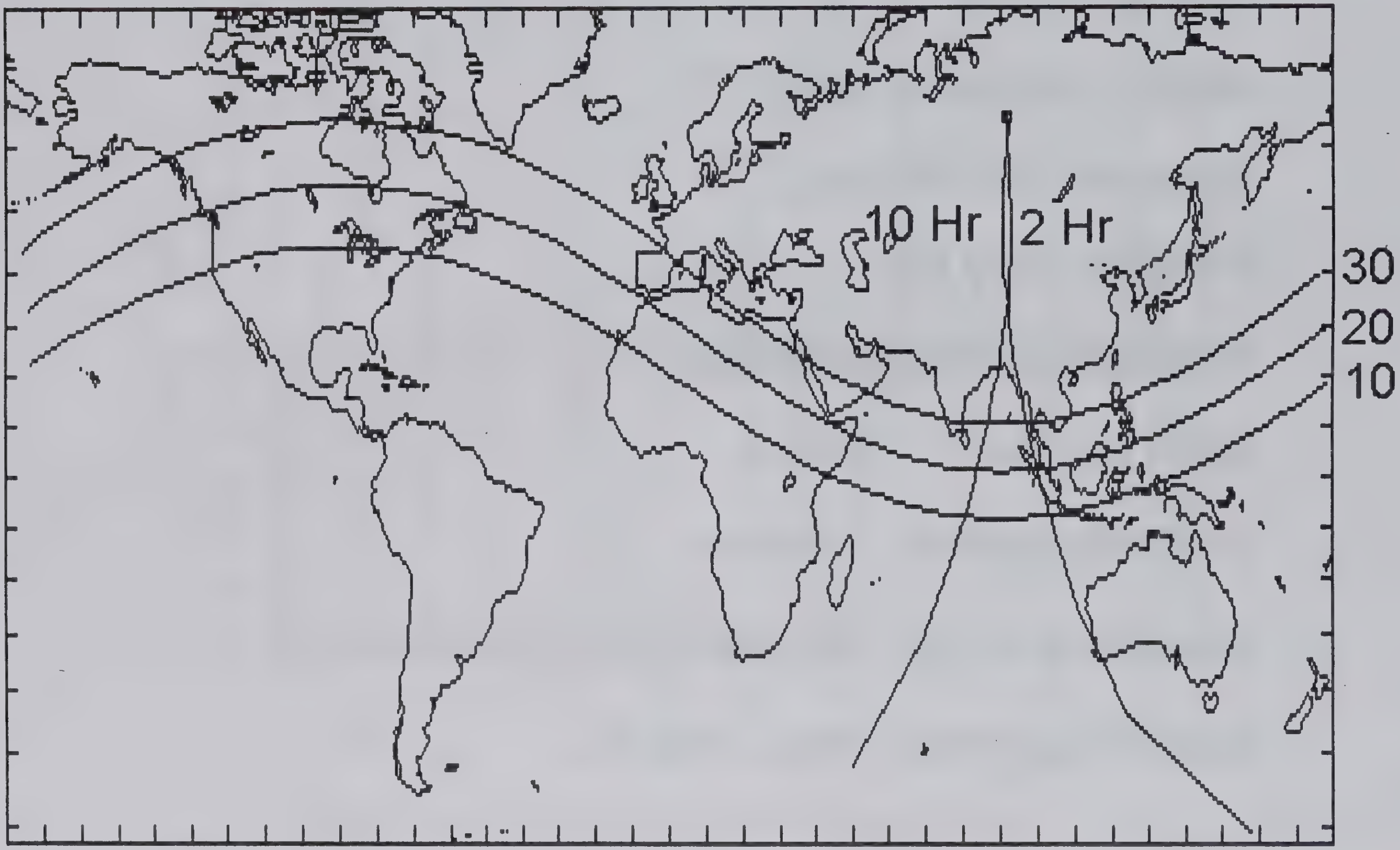
Orbit period - 12 hours

Visibility period - 8 hours

Maximum range - 44,040 km (10° elevation)

Round trip delay time - 294 ms

HEO
Groundtrack and Visibility



HEO Advantages/Disadvantages

2A- 18

Advantages

- Purpose is to cover northern latitudes
- No solar outage

Disadvantages

- Three satellites required to provide 24 hour coverage
- Satellite hand-off required
- Earth station must track satellites (but not very much

LEO Orbit Parameters

Teledesic system as reference

Circular orbit

Altitude - 1350 km

Inclination - 90°

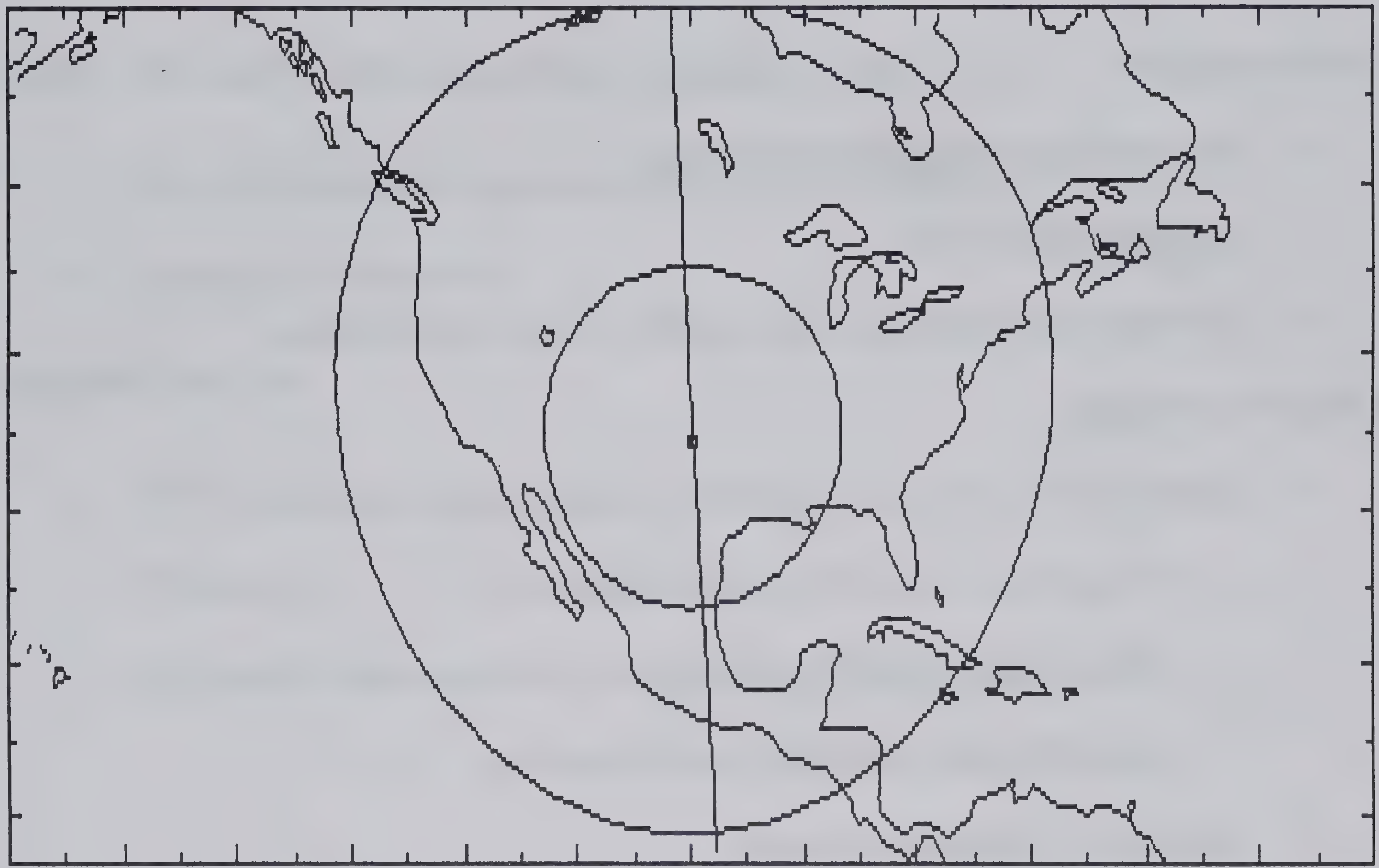
Orbit period - 1.88 hours

Visibility period - 16 min. 10° elevation
6.7 min. 40° elevation

Maximum range - 1888 km 40° elevation

Round trip delay time - 12.6 ms

LEO
Groundtrack and Visibility



LEO Advantages/Disadvantages

2A- 21

Advantages

- **Shorter propagation delays**
- **Lower path loss**
- **Constellations can provide global coverage**

Disadvantages

- **Satellite in motion relative to ground station**
  - **Requires tracking antennas or**
  - **Wide beamwidth (low gain) antennas**
  - **Significant Doppler processing**
- **Smaller coverage area**

Sun-Synchronous Orbit

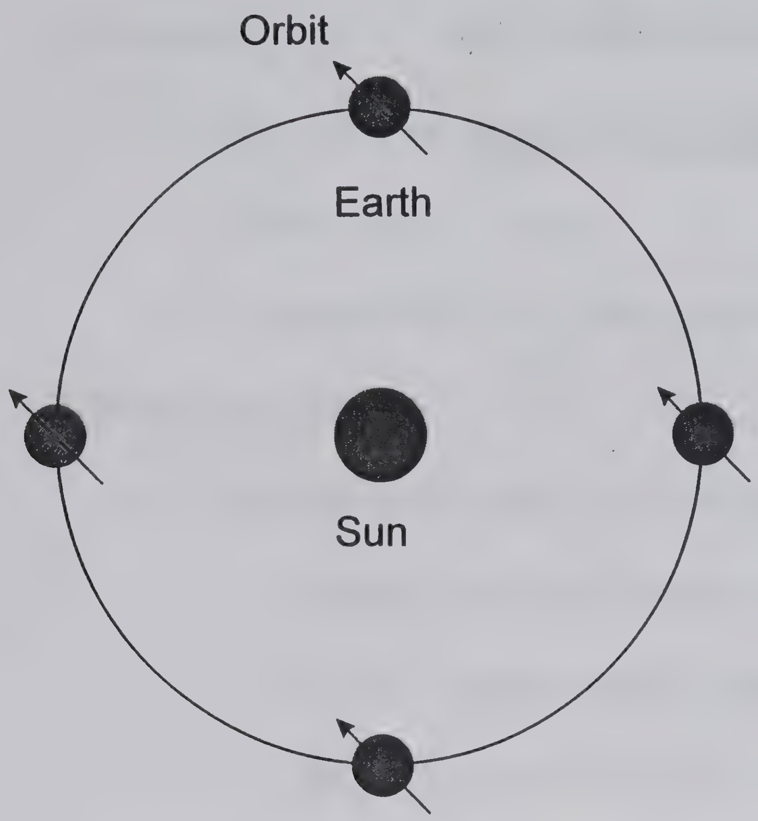
Earth not perfectly spherical (oblate spheroid)

- Nodal rotation (sun-synchronous orbit)
- Apsidial rotation

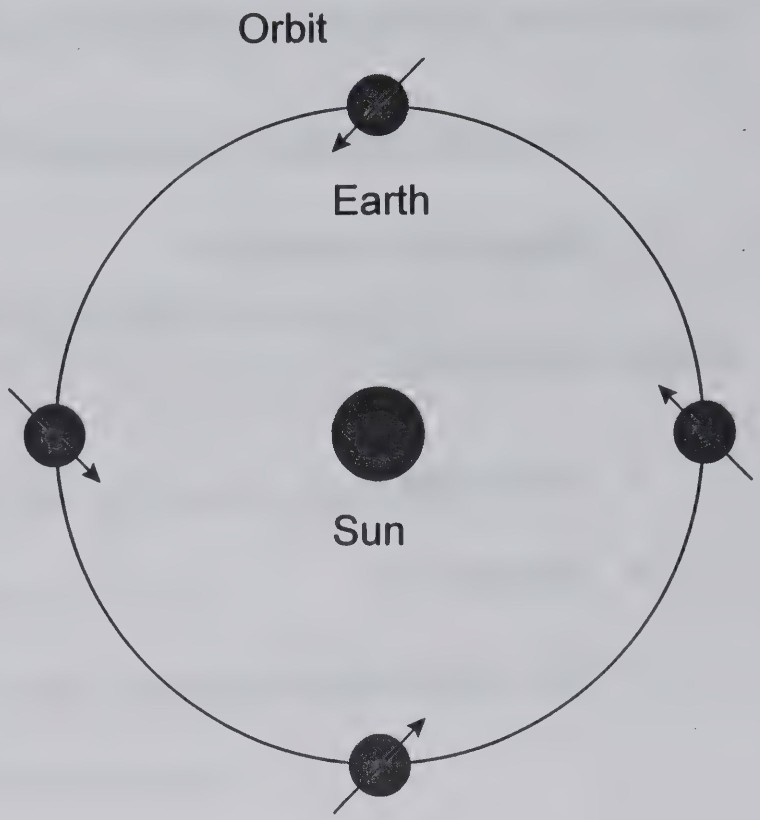
Dependent on

- Altitude
- Ellipticity
- Inclination

Spherical and Oblate Earth



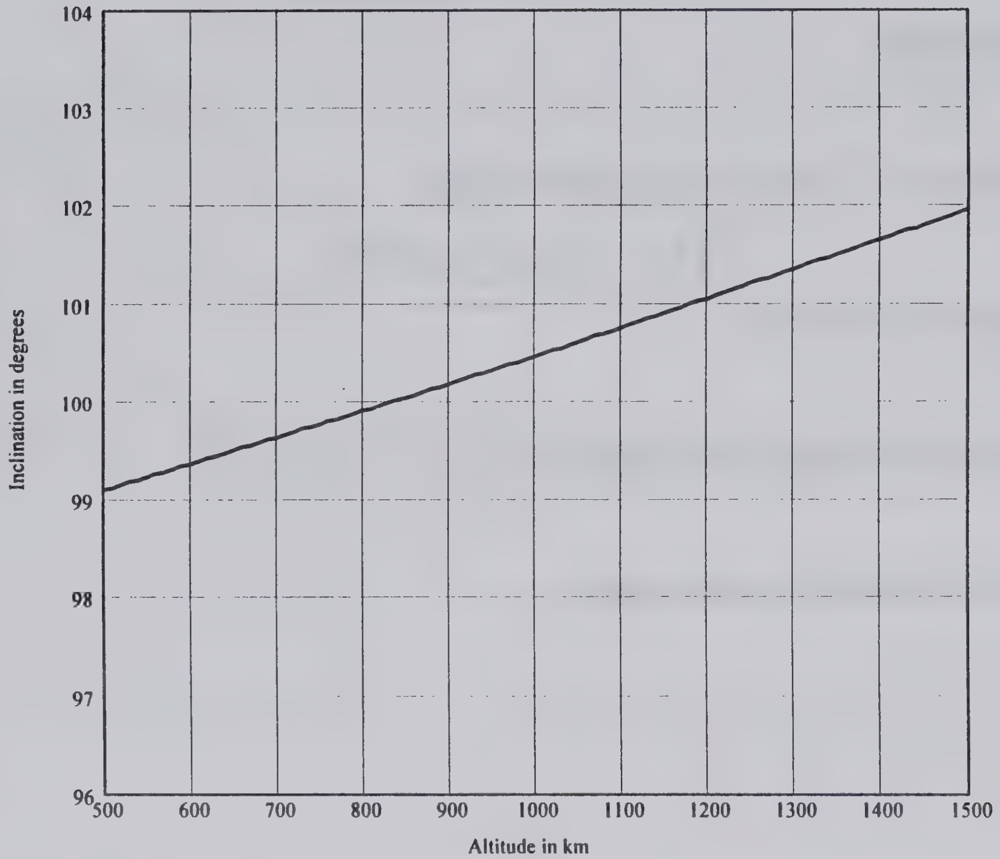
Spherical Earth



Oblate Earth

Sun-Synchronous Inclination

2A- 24



Orbital Effects Summary

Visibility

Antenna Tracking/pointing

Range (delay)

Range-rate (Doppler)

Operational outages

Commercial Satellite Communication Applications
Course No. 9SV109

Module 2B

Bus Subsystems

Satellite Bus Subsystems

- Attitude Control
- Electrical Power
- Command and Data Handling
- Propulsion
- Structures and Mechanisms
- Thermal Control
- Tracking, Telemetry, and Command (Module 2-4)

Attitude Control Options

2B- 3

- **Tumbling**
- **Gravity Gradient**
- **Body Stabilized**
- **Spin Stabilized**

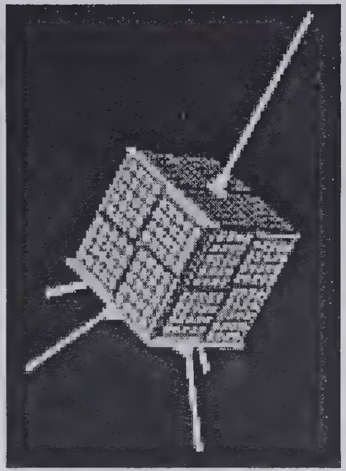
2B- 4

Attitude Control - External Torques

Source	Height range over which it is potentially dominant
• Aerodynamic	< about 500 km
• Magnetic	500 to 35,000 km
• Gravity gradient	500 to 35,000 km
• Solar radiation	> synchronous
• Thrust misalignment	all heights

Tumbling

- **No attitude control required**
- **Omnidirectional antennas required**

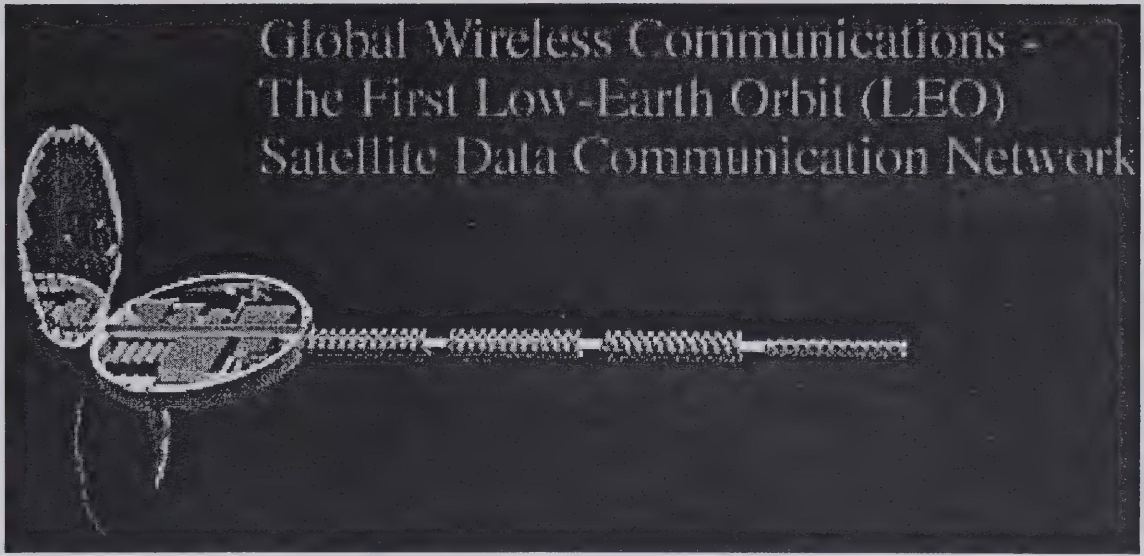


Amsat - Oscar Satellite

Gravity Gradient

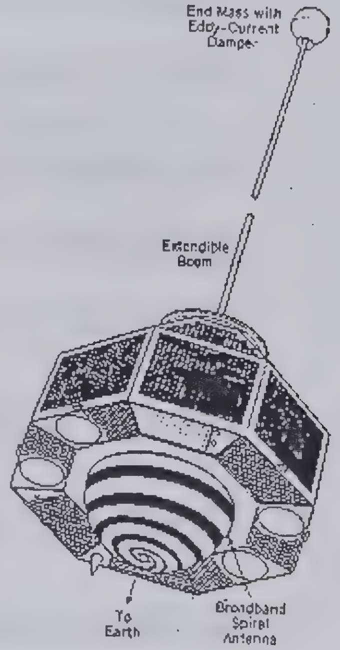
- Differential gravity produces torque to keep satellite Earth (nadir) oriented
- Does not require: sensors, power, actuators
- Does require: long booms, tip masses, damping devices
- Stabilization accuracy: ~ 5°
- Examples: ORBCOMM and GOES II satellite

Gravity Gradient Satellites



Global Wireless Communications - The First Low-Earth Orbit (LEO) Satellite Data Communication Network

ORBCOMM Satellite

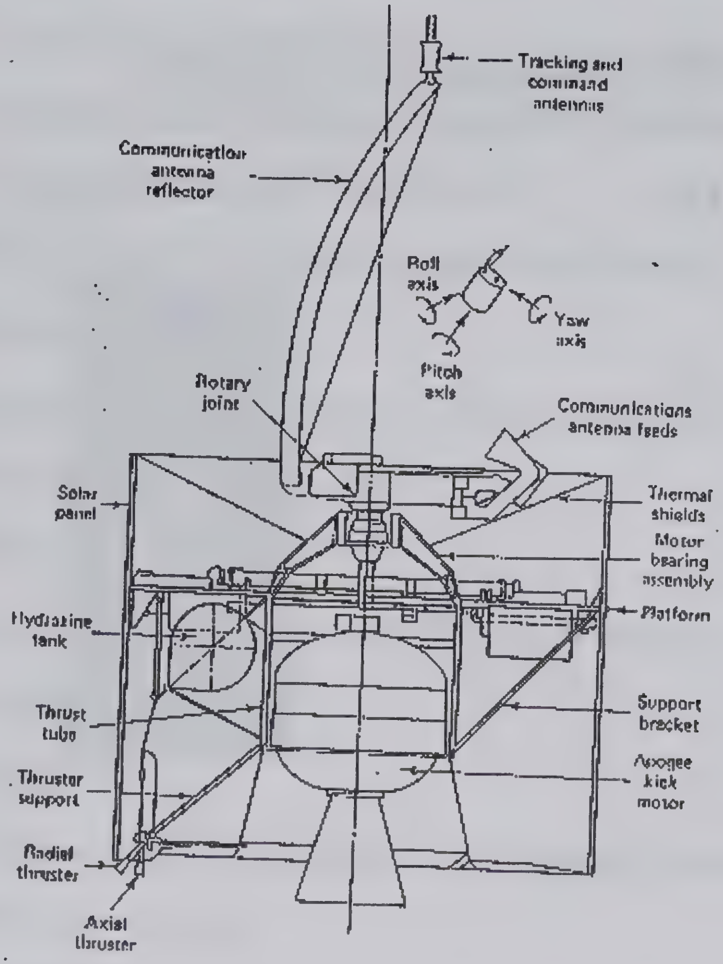


GOES II

Spin Stabilization

- **Passive stabilization: Rotate around axis with maximum moment of inertia (Leasat)**
- **Active nutation damping: Do not rotate around axis with maximum moment of inertia (HS-376)**
- **30 to 100 rpm**
- **Requires sensors**
- **Antennas**
  - **Omnidirectional**
  - **Toroidal**
  - **Despun antenna suite**

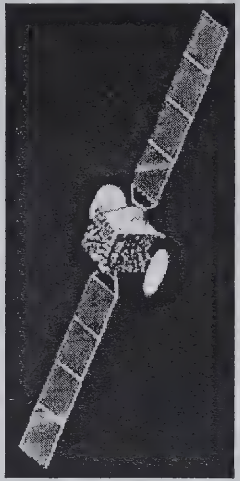
Spin Stabilization



Anik A Satellite

Body Stabilized

- Fixed orientation with respect to Earth
- Rotate once per orbit
- Requires sensors
- Antennas
  - Anything goes
- Examples
  - Hughes HS-601
  - Lockheed-Martin LM AX2100



Attitude Determination

- Earth horizon sensor
  - Accuracy depends on satellite altitude
  - 0.1 degree at GEO altitude
  - Error due to atmosphere fuzziness
- RF Sensor
  - Accuracy depends on frequency and reflector size
  - Not as useful for LEO
- Sun Sensor
  - Satellite may not always have view of sun
  - Accurate
- Star Sensor
  - Images star field and finds designated star
  - Very accurate

Types of Attitude Control

- Magnetic torquers
  - Small satellites (very low torque)
  - Aligns magnetic rod with Earth's magnetic field
- Momentum wheels
  - Useful on larger satellites
  - Adjust satellite attitude using electrical power to torque on spinning wheels
- Thrusters
  - Requires additional fuel (bang-bang)
  - Typically operated in coupled pairs
- Active nutation damping
  - Used on spinning satellites
  - Adjust satellite attitude using electrical power to torque on spinning section of satellite
- Solar pressure

Electrical Power

Power Vs. Mission Duration

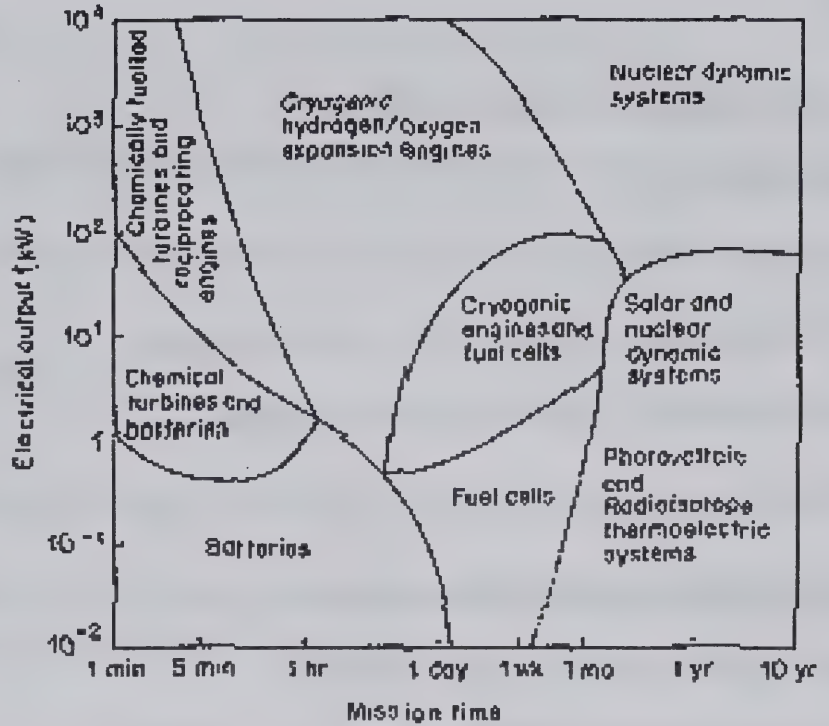


Figure 11.2 Power outputs: mission duration relationship between *energy source and appropriate operational scenario* [3]. (Reproduced with permission from Angrist, S.W. (1982) *Direct Energy Conversion*, 4th edn, Allyn and Bacon, New York)

Electrical Power

- **Solar power**
  - **1400 watts per square meter at Earth**
  - **Solar cell efficiency:**
    - **Silicon: 12 to 13%**
    - **Gallium Arsenide: 19 to 22% and higher**
  - **Requires batteries for periods of eclipse**
- **Nuclear power**
  - **52 watts per square meter at Jupiter**
  - **3.8 watts per square meter at Uranus**
  - **Radioisotope Thermoelectric Generator (RTG)**
    - **Voyager/Galileo/Ulysses/Cassini**
    - **No batteries required**

Solar: Spinner Vs. Flat Panel

- **Spinner**
  - Drum solar array requires about 3 times (π) as many cells
  - Cells run cooler due to rotation (higher efficiency)

- **Flat panel**
  - Fewer cells required (lower weight and cost)
  - Typically must be deployed and steered toward sun (control/ reliability issues)

Batteries

- Supply power during eclipses
- Significant portion of weight
- Cannot be recharged an indefinite number of times

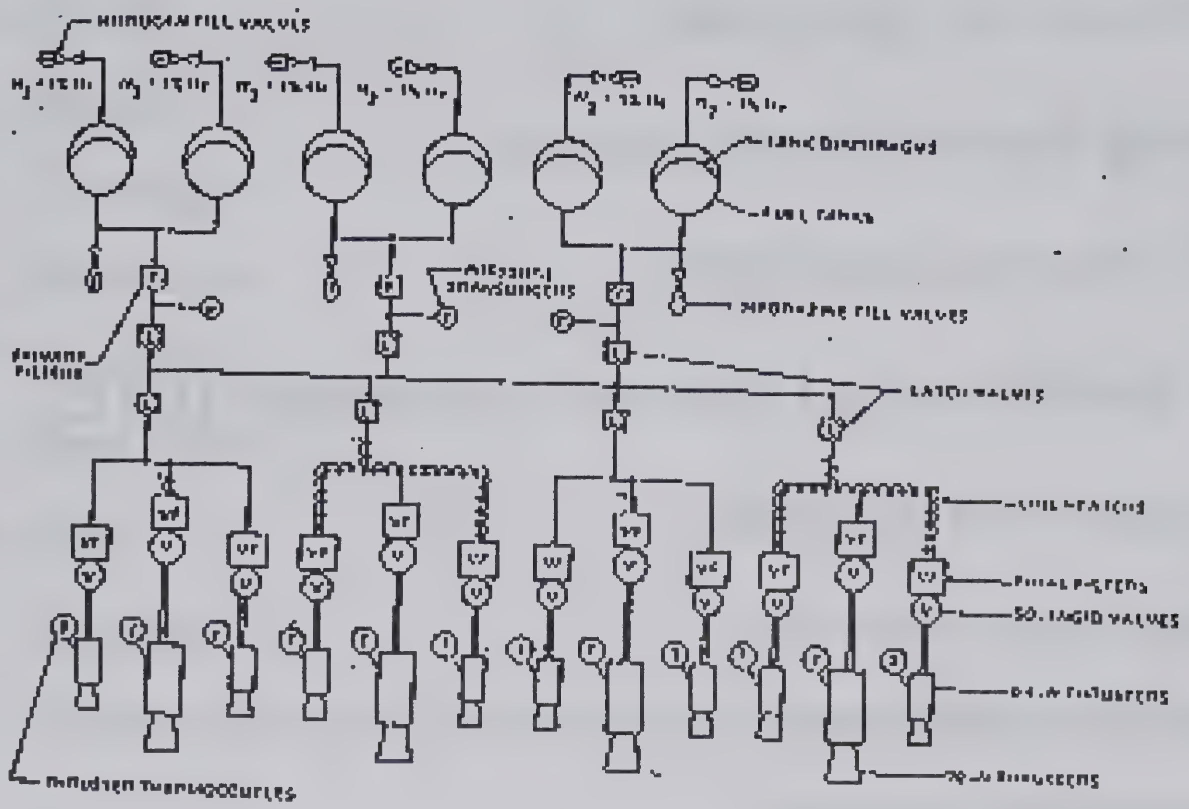
Command & Data Handling

- Nervous system of the satellite
- Processor based with data bus architecture
- Receive commands from the TT&C subsystem
- Distribute commands to other subsystems including communications payload
- Collect health and status information for delivery to TT&C
- Gather data from attitude control sensors/drive attitude control actuators

Propulsion

- Solid
    - Perigee kick motors
    - Apogee kick motors
- Liquid
    - Bipropellant - MMH & N_2O_4
    - Monopropellant - Hydrazine
    - Arcjet - Hydrazine
- Electric
    - Xenon propellant
    - Very efficient

Propulsion Schematic



IUE Hydrazine System

Structures & Mechanisms

- **Aluminum or graphite**
- **Moving toward fewer pieces**
- **Stiff, strong, and light**
- **Low coefficient of thermal expansion (CTE)**
- **Mechanisms include:**
    - **Solar array positioners**
    - **Antenna positioners**
    - **Deployment actuators**

Thermal Control

- **Passive**
    - **Paints**
    - **Coatings**
    - **Radiators**
    - **Insulation**
    - **Heat pipes**
- **Active**
    - **Louvers**
    - **Thermostatically controlled heaters**

Notes

Commercial Satellite Communication Applications
Course No. 9SV109

Module 2C
Communications Subsystems

October 24, 1997

Boeing Information, Space, & Defense Systems

Module Objectives / Assessments

2C- 2

What you can learn in this module:

- **What are the different types of satellite communications subsystems**
- **What are the main parameters of antennas that need to be considered in satellite systems**

How to measure your success:

- **Can you describe three communication subsystem types that are used on Boeing projects?**
- **What is the relationship between antenna size, beamwidth and gain?**

Communication Subsystem
Key Parameters

- Bandwidth
    - Limited Quantity (Restricted)
    - Information throughput
    - Revenue
- Power/Efficiency
    - More bandwidth requires more power
    - Additional power is additional cost
- Reliability
    - Lifetime

Comm Subsystem Type

Repeater transponder

- **Bent pipe**
- **Satellite switched TDMA**
- **Digital processing repeater**

Regenerative transponder

Simplex Downlink

Bent Pipe Transponder

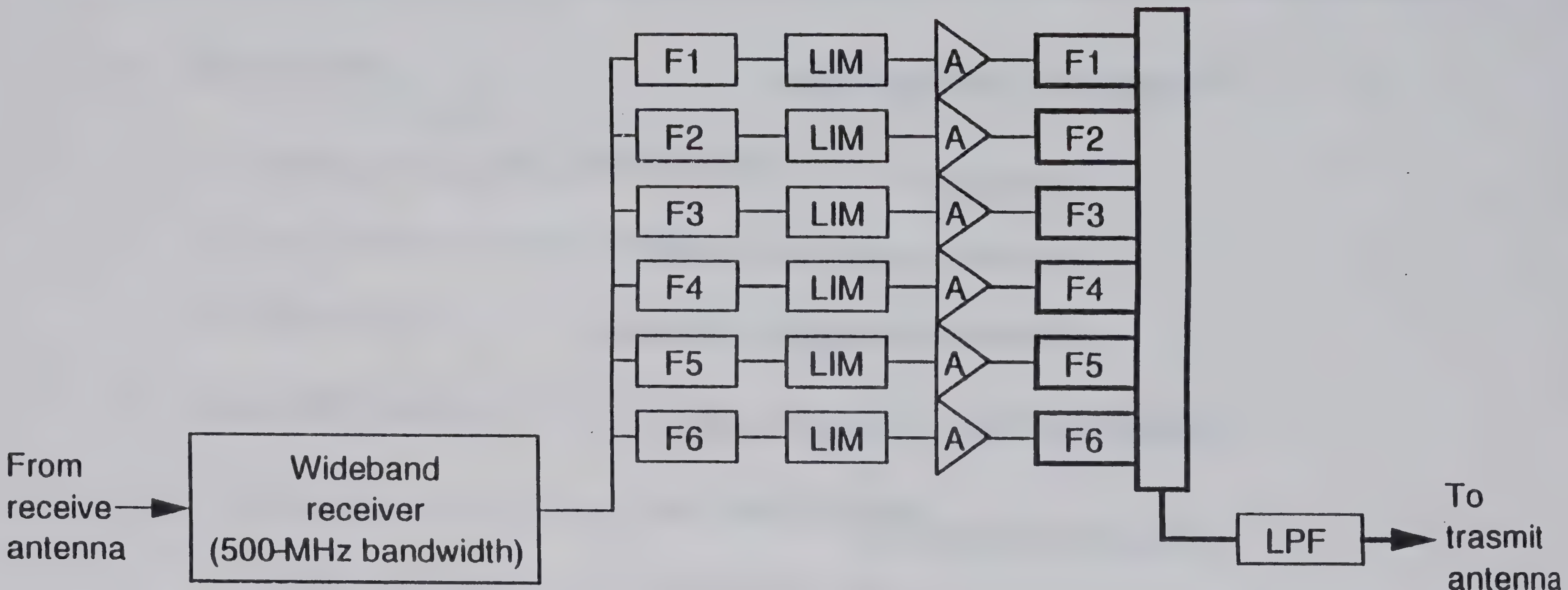


Figure 3.6 A simple bent pipe with six transponder channels, each transmitting approximately 72 MHz.

Bent Pipe Characteristics

Table 3.2

Typical Transponder Characteristics in a Bent-Pipe Repeater

Characteristic	*Typical Value*
Gain (saturation flux density)	–80.0 dBW/m^2
Linearity for multiple carriers (C/IM)	12 dB at saturation
Noise power ratio (NPR)	16 dB at 4 dB output backoff
Nonlinear phase shift (AM to PM conversion)	3 deg/dB
Amplitude frequency response (gain flatness)	±0.25 dB over useful bandwidth
Out-of-band attenuation (input channel separation)	–30 dB in adjacent channel
Cross-polarization isolation (XPOL)	30 dB (linear)
Multipath performance	dependent on overall design
Frequency tolerance and stability	10^{-6} in the translation frequency
Gain stability	±1.5 dB over lifetime

Signal and Transponder Characteristics

Table 3.3

Specific Signal Types and the Transponder Characteristics That Can Be Optimized for Improved Performance

Signal Type	*Transponder Characteristic*
FM Video	TWT AM/PM and filter group delay characteristics
Wideband digital data	Gain slope and nonlinear phase shift
SCPC	Gain flatness and linearity (NPR)
Wideband TDMA	Linearity, gain flatness, and transient response of the power supply
VSAT Operations	Gain flatness/linearity and frequency stability
Mobile SCPC	Frequency stability and NPR

Power Amplifiers

2C- 8

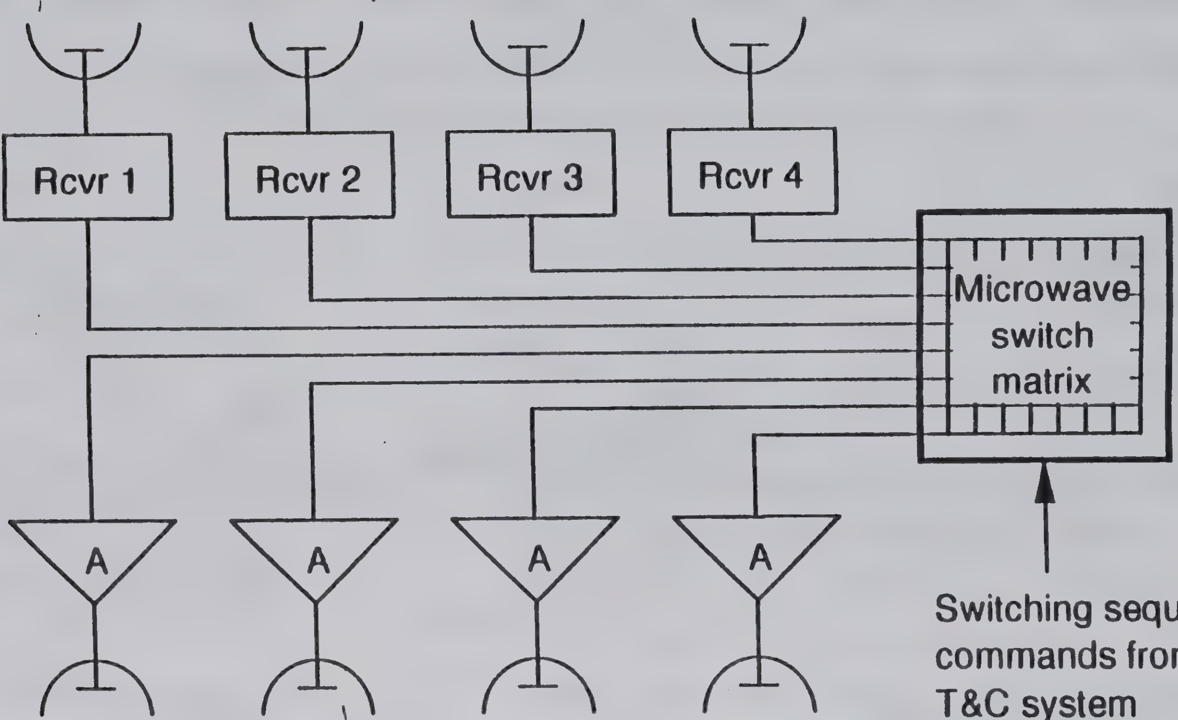
Table 3.1

Comparison of Spacecraft Power Amplifiers Using Typical Values, Without Linearization

Characteristic	*TWTA*	*SSPA*
Frequency bands	L through Ka	L through Ku
Power output	10W to 200W	5W to 30W
Bandwidth	20%	5%
Gain	40 dB to 60 dB	6 dB to 20 dB (input driver amplifier can be added)
Efficiency	40 to 60%	30 to 40%
Weight	1.5 kg to 5.5 kg	1 kg to 2 kg
Linearity		
C/IM at maximum power	12 dB	16 dB
AM to PM conversion	5 deg/dB	2.5 deg/dB
Maximum phaseshift	40 deg	20 deg
Operating temperature	60°C	30°C

Satellite Switched TDMA

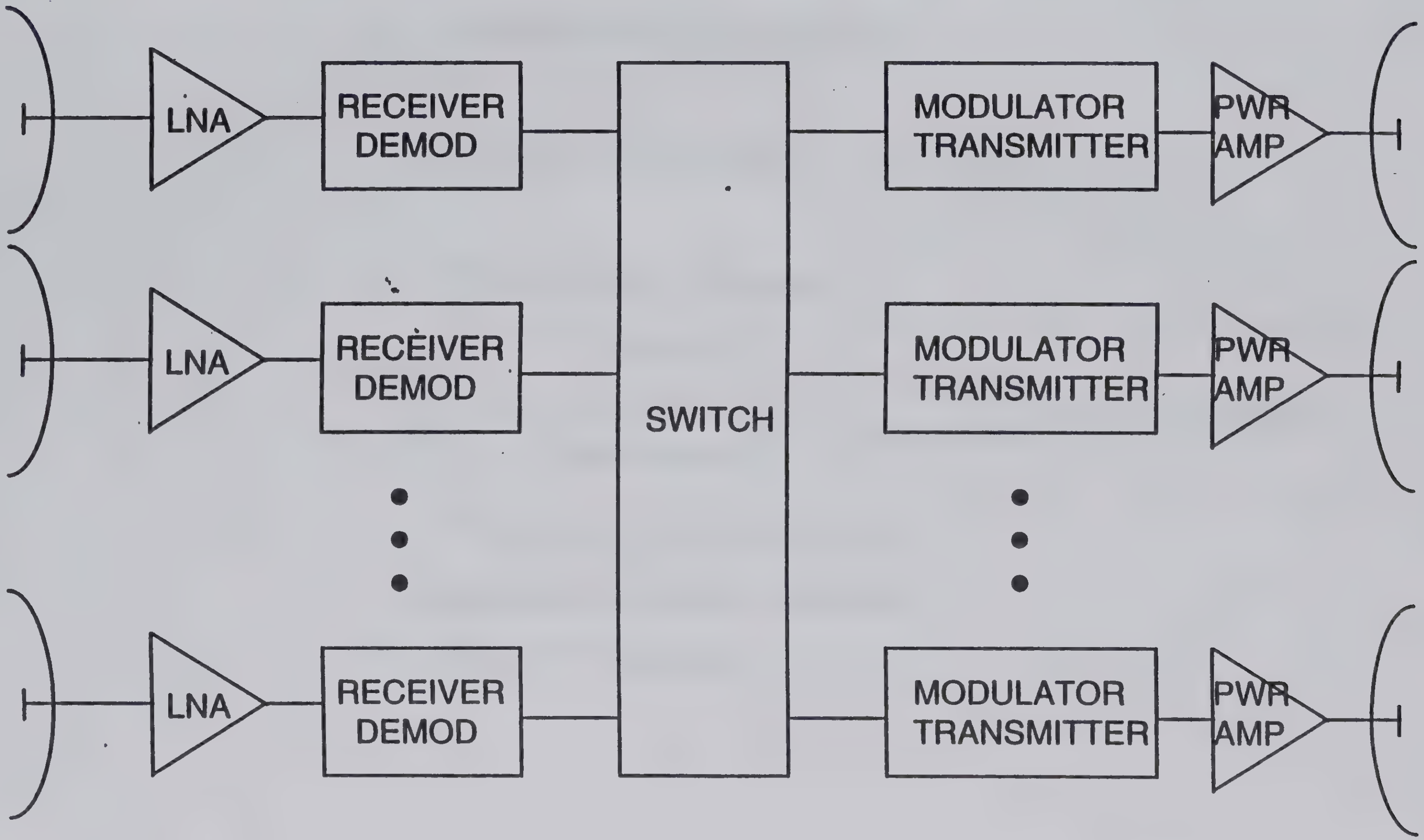
Individual receive spot beams, one per region



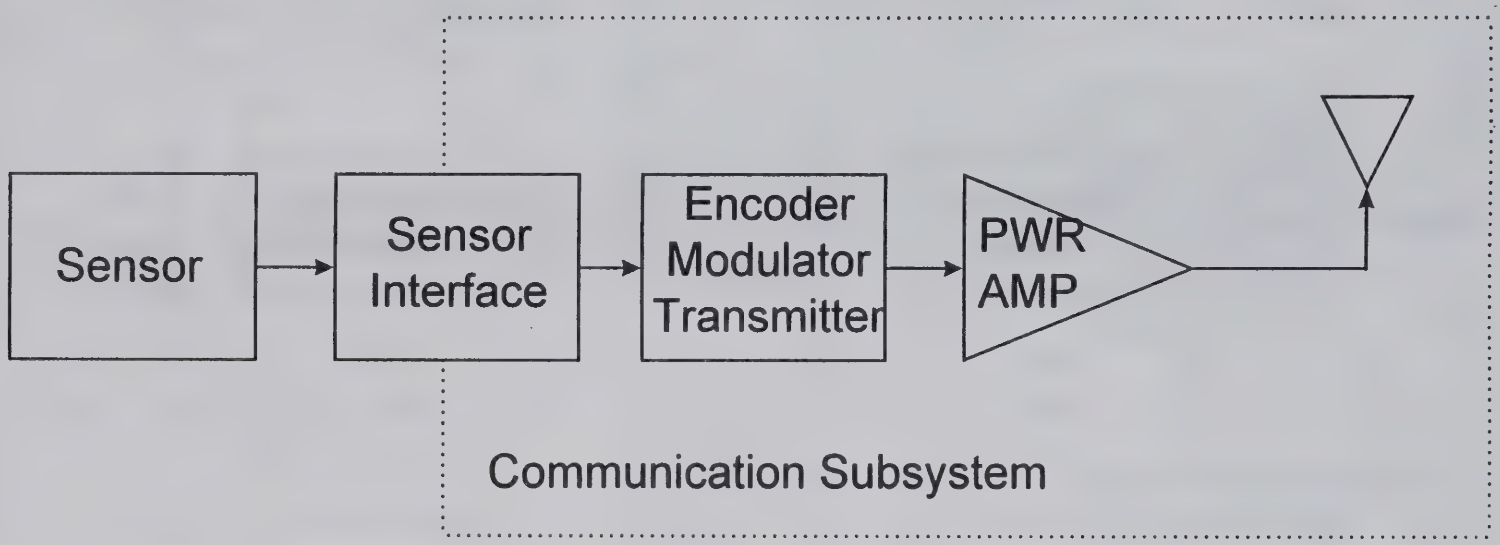
Switching sequence commands from T&C system

Individual transmit spot beams, one per region

Regenerative Transponder



Simplex Downlink



Sensor

Sensor Interface

Encoder
Modulator
Transmitter

PWR
AMP

Communication Subsystem

Antenna Configurations

2C- 12

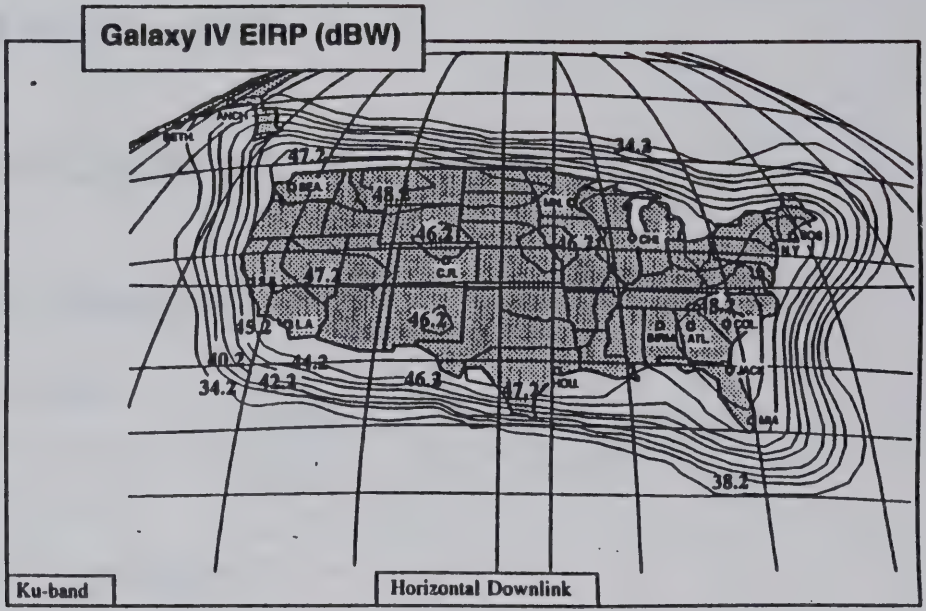
- **Wide Area Coverage**
- **Spatial Diversity**
- **Frequency Reuse**

- **Tracking (gimballed)**
- **Nadir Staring**

Wide Area Coverage

2C- 13

- **Good for broadcast**
- **Good for mesh network connectivity**
- **Number of network customerstypically limited by overall bandwidth**

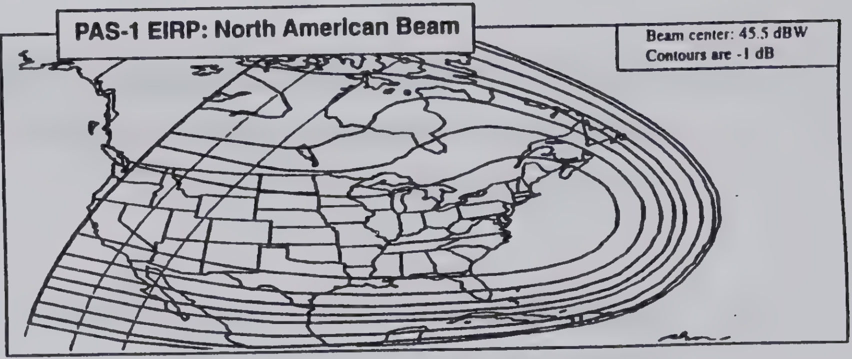


Spatial Diversity

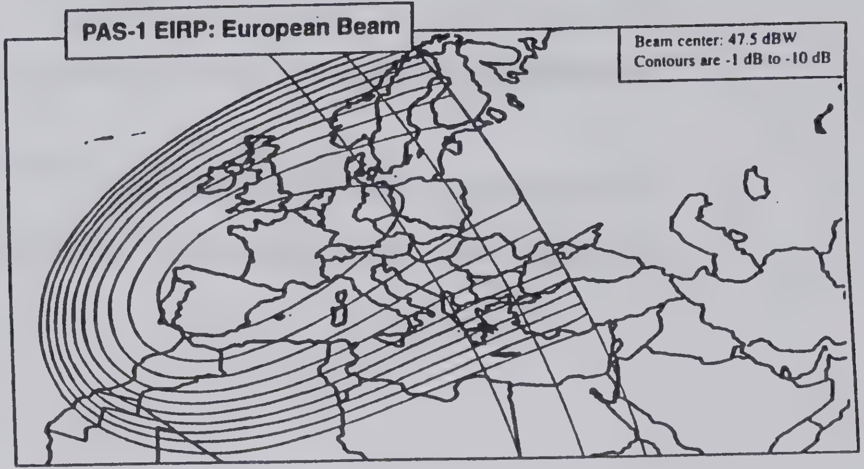
2C- 14

- **Reuse frequencies on antennas whose beams don"t overlap**

- **PANAMSAT uses separate beams for North America and Europe**


PAS-1 EIRP: North American Beam

Beam center: 45.5 dBW
Contours are -1 dB


PAS-1 EIRP: European Beam

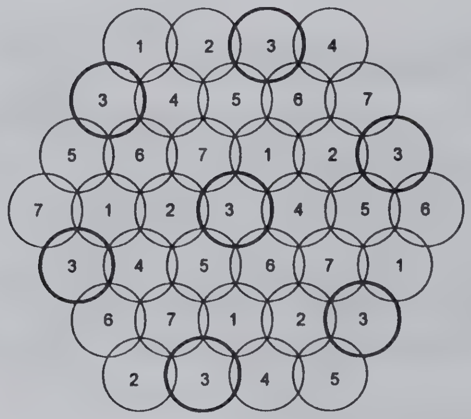
Beam center: 47.5 dBW
Contours are -1 dB to -10 dB

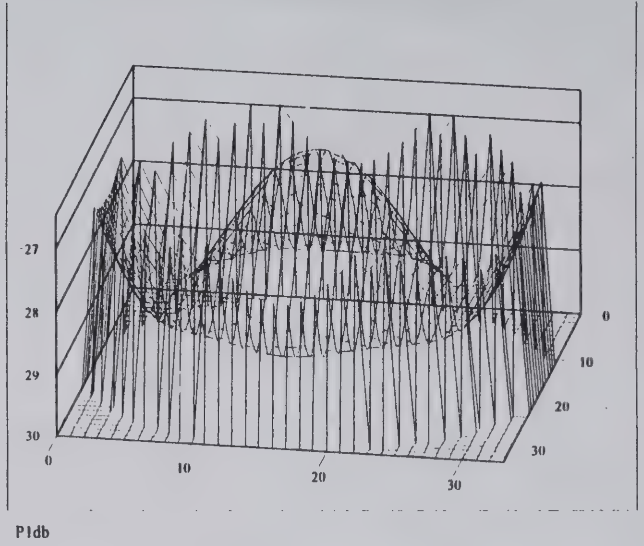
Frequency Reuse

- **Overlapping beams use different frequencies to avoid interference**

- **Interference level depends on antenna sidelobes and separation of beams using same frequency**

- **Same frequencies can be reused on nonadjacent beams**





Tracking vs Nadir Staring

2C- 16

- **Non-Geostationary-Orbit (NGSO) satellites move relative to a point on earth**
- **Satellite antennas**
  - **Track a point on earth (gimballed antenna)**
    - **Beam shape typically changes during satellite pass**
  - **Drag beams over earth's surface (nadir staring)**
    - **Beam shape constant**

Antenna Characteristics

Antenna is transducer

- Electrical to electromagnetic
- Electromagnetic to electrical
- Most antennas are reciprocal

Important features

- Gain
- Beamwidth

Directivity

- Bandwidth
- Polarization
- Efficiency

Directivity

Directivity $= \frac{4\pi A_e}{\lambda^2}$

A_e is Effective aperture area

$A_e = \eta A$

η is aperture efficiency

λ is wavelength

For a dish antenna with a circular aperture

$$A = \pi r^2 = \frac{\pi d^2}{4}$$

$$\text{Directivity} = \eta \pi^2 \left[\frac{d}{\lambda}\right]^2$$

Gain/Beamwidth

Gain

Gain = e_{cd}*Directivity

$e_{cd} = e_c * e_d$

e_c = conductive efficiency

e_d = dielectric efficiency

Beamwidth

$$D_o \sim \frac{41253}{\theta_1 \theta_2} \sim \eta \, \frac{\pi d}{\lambda}^{\,2}$$

$$\theta \sim 64.6 \, \frac{\lambda}{d} \qquad \text{for } \eta = 1$$

θ is the half-power beam width (HPBW) (width of beam at - 3 dBic)

Bandwidth

Not all antenna parameters affected the same by frequency

Gain

Pattern

Impedance

Polarization

Narrowband antenna bandwidth specified as % of center frequency (5%)

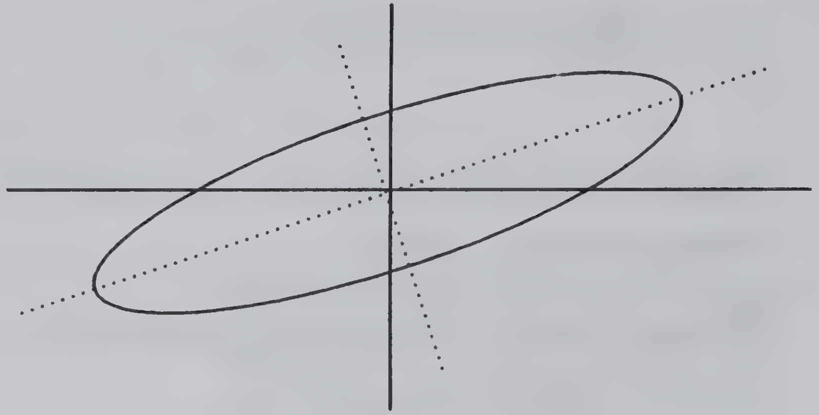
Broadband antenna bandwidth specified and ration of upper to lower frequency (2:1)

Typical communication antennas are narrowband < 10% bandwidth

Polarization

- **Direction of electric field vector**
- **Polarization is generally elliptic, special cases are linear and circular.**
- **Axial ratio is measure of ellipticity of polarization**

$$r = \frac{\text{major axis}}{\text{minor axis}}$$



- **Polarization vectors of transmit and receive antennas must align for maximum transfer of power**

Polarization Diversity

2C- 22

- **Transmit two channels over same frequency using orthogonal polarization**
- **Orthogonality required**
  - **25 dB for analog FM**
  - **17 dB for digital BPSK and QPSK**
  - **Greater separation required for more complex digital signals**

20*Log(cos(L - R))

L - R = 3.22 degrees for 25 dB
L - R = 8.17 degrees for 17 dB

Efficiency

2C- 23

Ratio of actual power delivered to maximum power available

Affected by

- **Aperture efficiency**
- **Impedance matching**
- **Ohmic losses**

Earth Coverage Horn

2C- 24

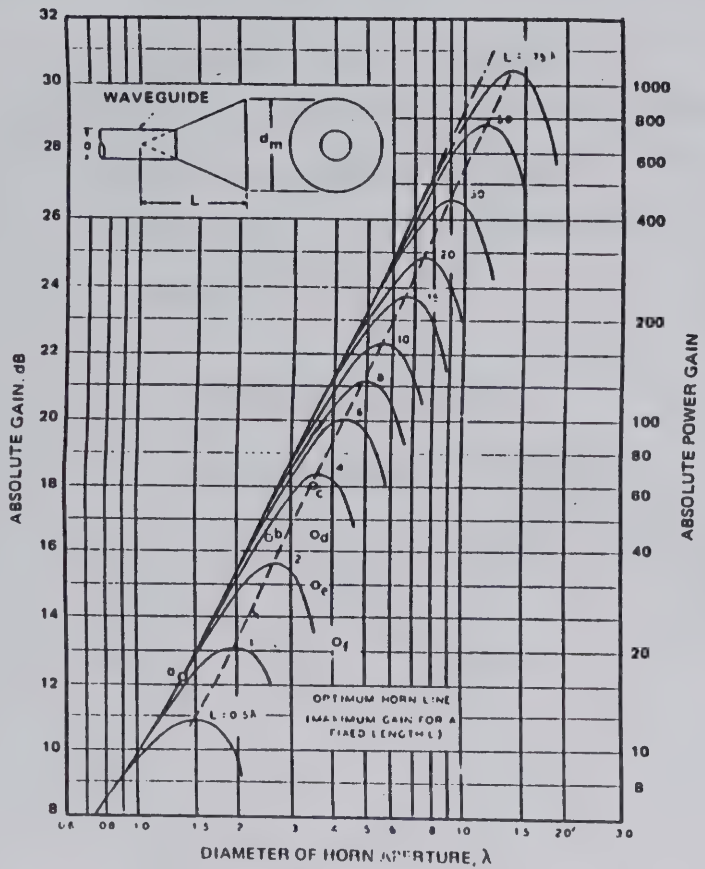
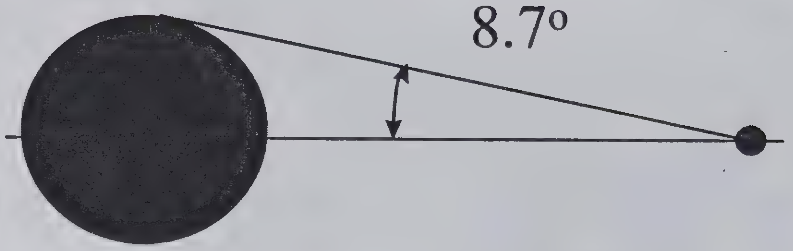


FIG 15-10 Calculated gain of a conical horn as a function of aperture diameter with axial length as parameter (© 1950 IEEE; see Ref 17.)



θ = 17.4 degrees

$$G \sim \frac{41253 * ff}{\theta^2}$$

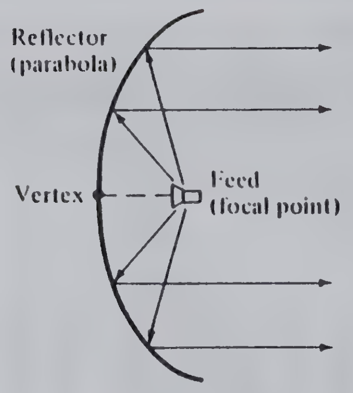
G ~ 18 dB

Parabolic Reflector

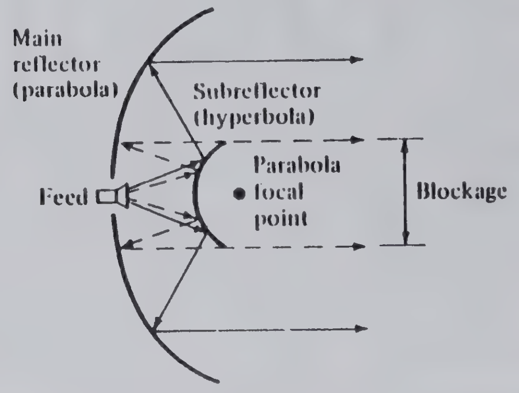
- Typically high-gain antennas
- $\frac{d}{\lambda} > 10$

$$G = 20.4 + 10\,\mathrm{Log}(n) + 20\,\mathrm{Log}(f) + 20\,\mathrm{Log}(D)$$

f in GHz
D in meters



(c) Curved (front-fed)

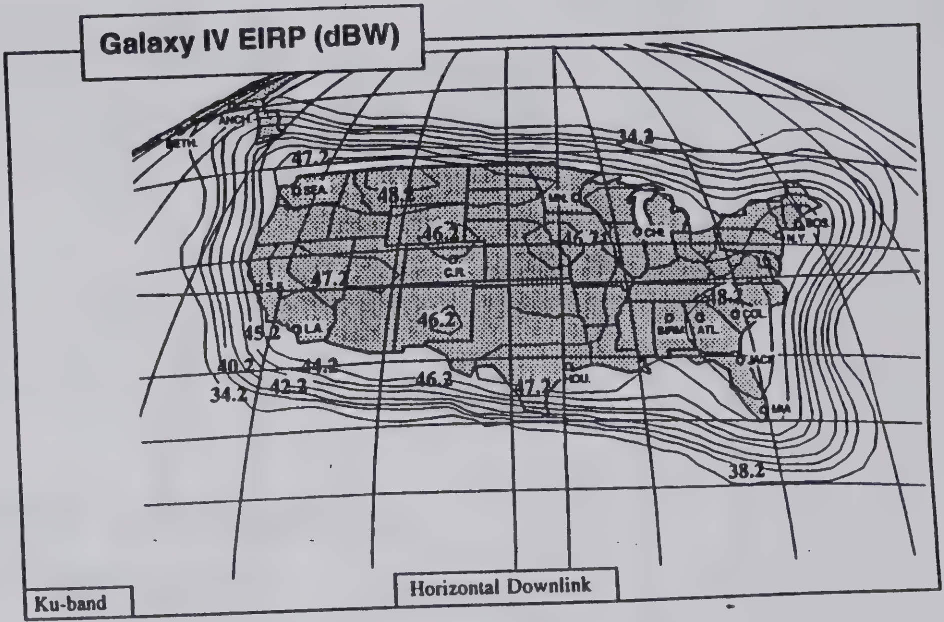


(d) Curved (Cassegrain feed)

Shaped Beam Antennas

2C- 26

- **Shape antenna beam to provide energy where needed and not spill over into adjacent unpopulated or restricted areas**
  - **Shaped reflector**
  - **Multiple-feed shaping**


Galaxy IV EIRP (dBW)

TT&C Antenna

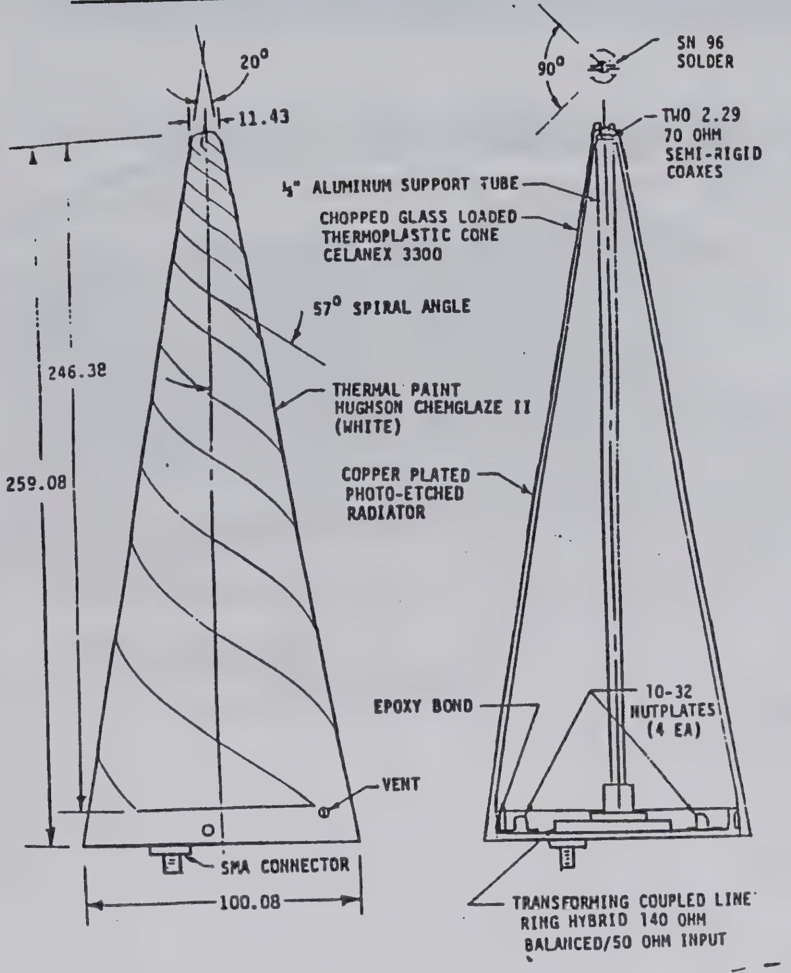
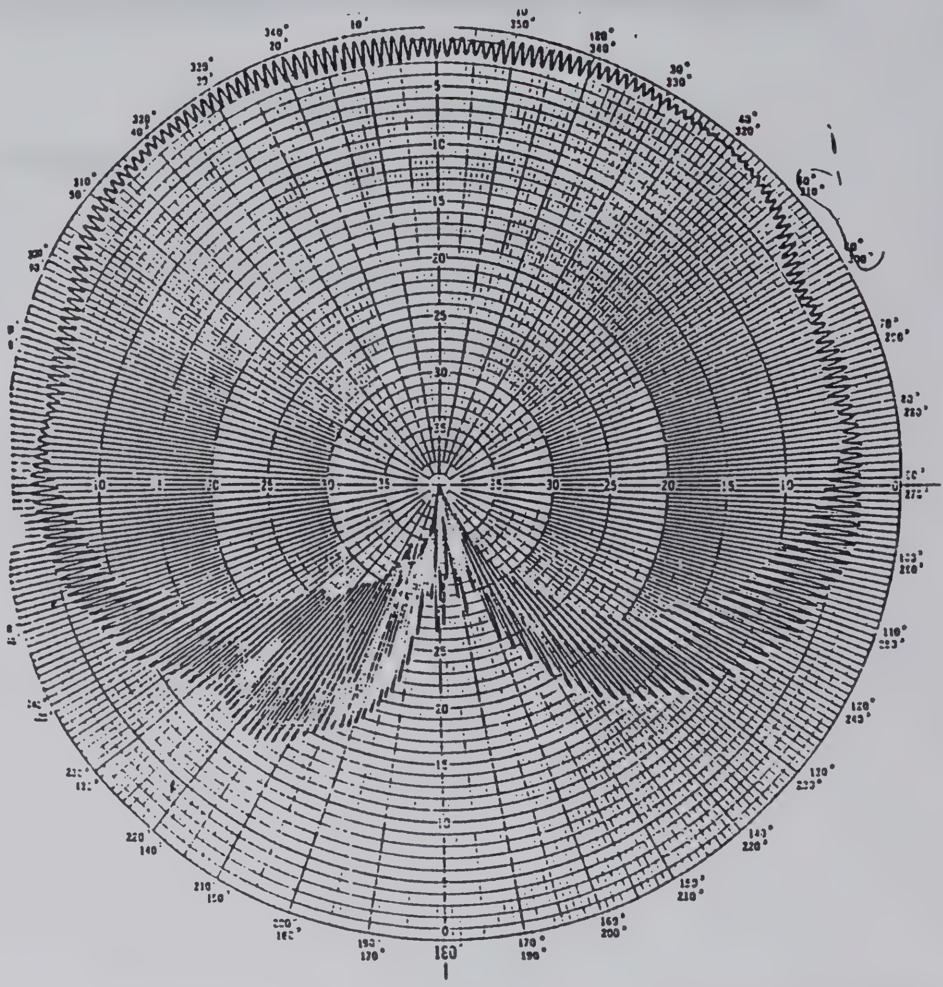


Figure 1.2.1.1 Conical Log Sprial Antenna Configuration For VIKING
(All Dimensions In Millimeters)



Communication Subsystem Summary

- **Bandwidth**
- **Power/Efficiency**
- **Reliability**

- **Transponder & antenna configuration optimized for type of service**

(Know Thy Customer)

Commercial Satellite Communication Applications

Course No. 9SV109

Module 2D
TT&C

October 24, 1997

Boeing Information, Space, & Defense Systems

Module Objectives / Assessments

2D- 2

What you can learn in this module:

- What function does the TT&C subsystem on a satellite perform

How to measure your success:

- What three aspects of a satellite operation are performed by the TT&C subsystem

TT&C

- **Telemetry - Health and status of satellite**
  - **Temperature**
  - **Power**
  - **Fuel**
  - **Switch Positions**
- **Tracking - Determination of orbit position**
  - **Range**
  - **Range rate**
  - **Azimuth and elevation**
- **Control - Command operation of satellite**
  - **Orbit adjustments**
  - **Fault recovery**
  - **Deployment**

Frequency Selection

2D- 4

- Some limited frequency bands set aside for space operations
- Normally, TT&C operations are done in communications band of satellite

Operational Modes

- **Typically two operational modes**
  - **Transfer orbit and contingency mode**
    - **Satellite attitude unknown or unstable**
    - **Use omni-directional antenna capability**
  - **Operational satellite**
    - **Satellite in nominal attitude**
    - **Use earth coverage or high-gain antenna**

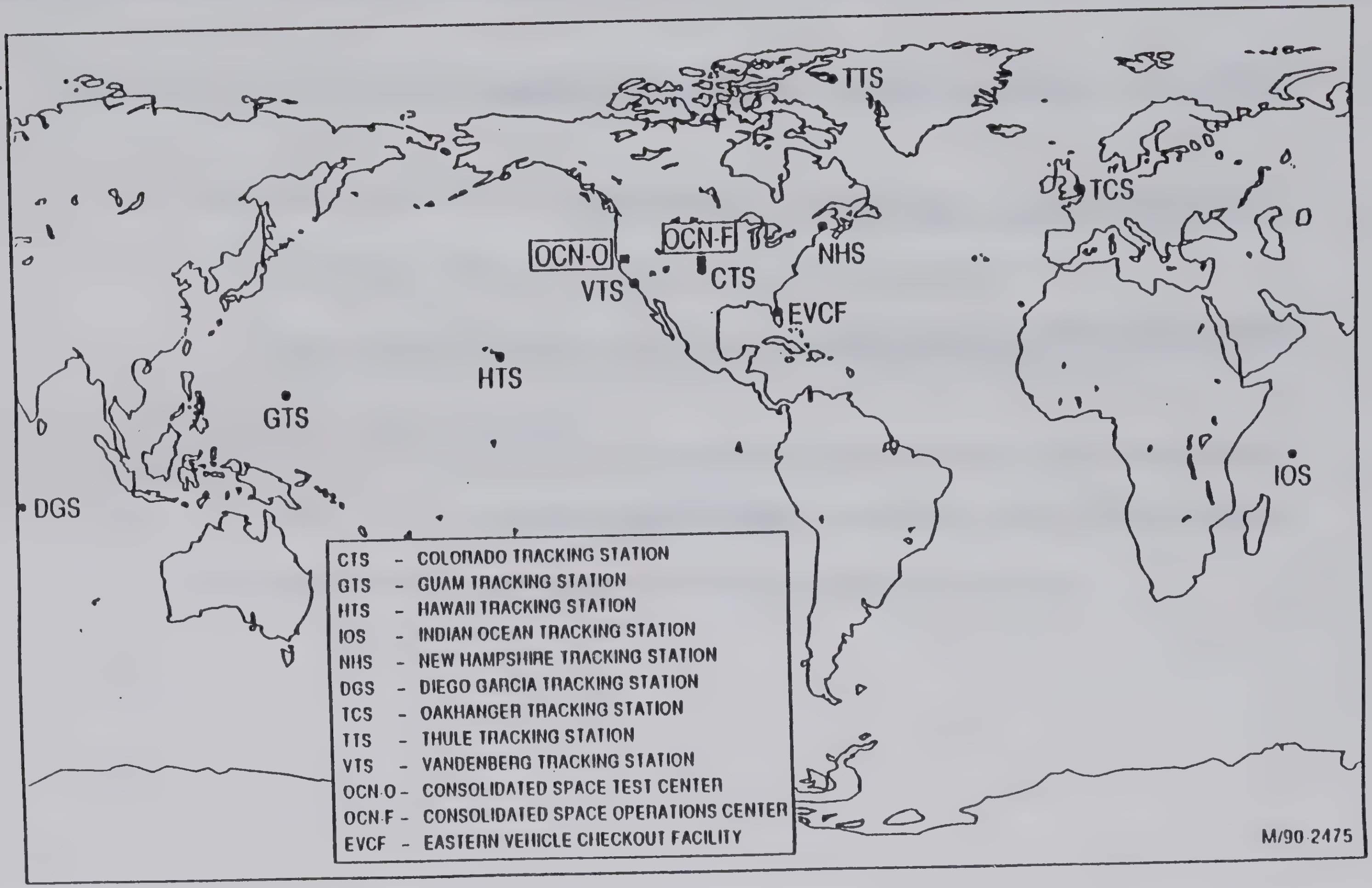
SGLS Example

2D- 6

- **SGLS - Space-Ground-Link-System**
- **DOD/Airforce standard for TT&C**
- **Worldwide coverage**
- **Additionally provides some limited payload downlink capability for military satellite users**

Network Ground Nodes

2D- 7


TTS
TCS
OCN-O
OCN-F
NHS
VTS
CTS
EVCF
HTS
GTS
IOS
DGS
CTS - COLORADO TRACKING STATION
GTS - GUAM TRACKING STATION
HTS - HAWAII TRACKING STATION
IOS - INDIAN OCEAN TRACKING STATION
NHS - NEW HAMPSHIRE TRACKING STATION
DGS - DIEGO GARCIA TRACKING STATION
TCS - OAKHANGER TRACKING STATION
TTS - THULE TRACKING STATION
VTS - VANDENBERG TRACKING STATION
OCN-O - CONSOLIDATED SPACE TEST CENTER
OCN-F - CONSOLIDATED SPACE OPERATIONS CENTER
EVCF - EASTERN VEHICLE CHECKOUT FACILITY
M/90-2475

Command Uplink

2D- 8

- **Data rate - 1kb/s and 2 kb/s**
- **Modulation - FSK multiplexed with PRN ranging code**
- **Encrypted**

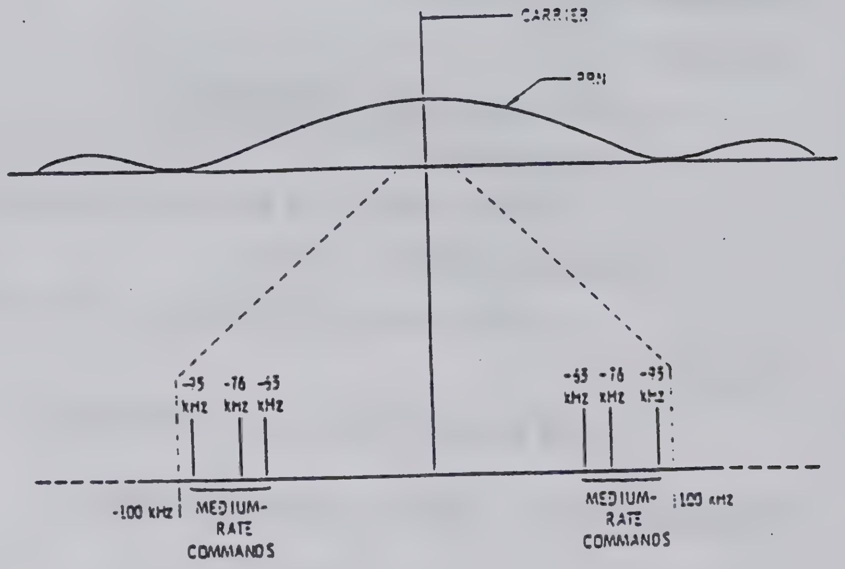


Figure 1-16. Typical Uplink Carrier Spectrum

Telemetry Downlink

2D- 9

Variety of services

Carrier 1

- PRN Downlink channel
- Subcarrier 1
  - PCM data, 7.8 b/s to 128 kb/s
- Subcarrier 2
  - PCM data, 125 b/s to 256 kb/s

Carrier 2

- PCM data, 128 kb/s 1.244 Mb/s

Modulation - phase modulation

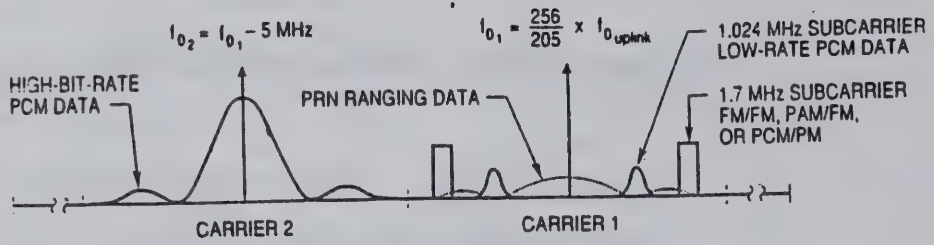

$f_{0_2} = f_{0_1} - 5$ MHz
$f_{0_1} = \frac{256}{205} \times f_{0_{uplink}}$
1.024 MHz SUBCARRIER LOW-RATE PCM DATA
HIGH-BIT-RATE PCM DATA
PRN RANGING DATA
1.7 MHz SUBCARRIER FM/FM, PAM/FM, OR PCM/PM
CARRIER 2
CARRIER 1

Figure 1-11. Typical SGLS Downlink Spectrum

Tracking

2D- 10

Two Tracking modes

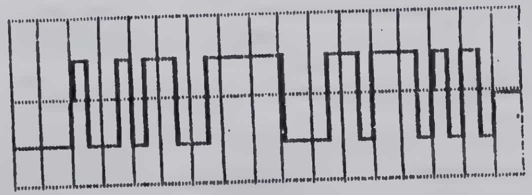
- Phase-lock tracking
- Cross-correlation tracking

PRN code at 1 MHz

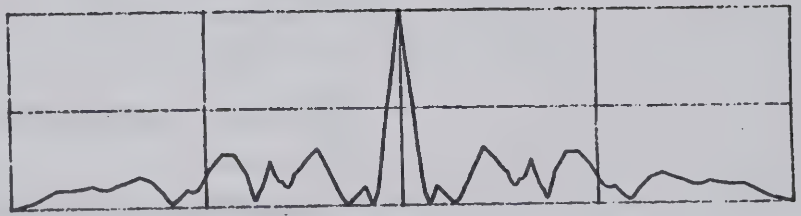
Accuracy dependent on orbit

Range accuracy better than 13 m

Range-rate accuracy better than 0.061 m/s



32 bit Sequence



Correlation output

Ranging Errors

Error Source	100,000 nmi (Worst Case)		50 nmi (Circular)		120 nmi (Circular		6,000 nmi (Circular)		150 to 60,000 nmi (Elliptical)	
	Bias ft	Noise ft	Bias ft	Noise ft	Bias ft	Noise ft	Bias ft	Noise ft	Bias ft	Noise ft
Receiver Noise*		3.0				0.4		4.0		21.0
Oscillator Noise	5.0		5.0		5.0		5.0		5.0	
Dynamic Errors										
Velocity	10.0		6.3				0.1			
Acceleration	15.4				2.5					
Phase Instability	13.8		13.8		13.8		13.8		13.8	
Quantization		2.3		2.3		2.3		2.3		2.3
Time Measurement	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Reflections	7.0		7.0		7.0		7.0		7.0	
Propagation	17.0**	0.3	2.0	0.3	6.0	0.3	17.0	0.3	8.0	0.3
Total RSS Error	31.5	31.7	20.2	10.3	20.2	10.3	25.6	11.0	20.7	23.4

+ Required ranging accuracy: 30 ft., rms, (-120 dBm carrier power at the parametric amplifier input neglecting propagation error, tropospheric bias error corrected).

* Downlink power budget assumes threshold occurs at 100,000 nmi range.

** Ionospheric and tropospheric bias errors corrected.

TT&C Summary

2D- 12

- **Used to**
  - **Monitor health and well being of satellite**
  - **Determining position and orbit**
  - **Control operation of satellite**
- **Two modes**
  - **Operational mode - high gain antenna**
  - **Contingency mode - omni-directional antenna**
- **Normally uses satellite communication frequency band**

Commercial Satellite Communication Applications
Course No. 9SV109

Module 3
Communications 101

October 24, 1997

Boeing Information, Space, & Defense Systems

3- 2

Module Objectives / Assessments

What you can learn in this module:

- What a link budget is and what are the parameters in the link budget
- What modulations are useful for the satellite channel and why
- Why is error correction coding useful
- What are the advantages and disadvantages of different multiple-access schemes
- What are the major requirements drivers in a satellite communication system

Module Objectives / Assessments

How to measure your success:

- **Can you identify the major gain and loss components in a link budget?**
- **Can you describe the major contributors to the system noise?**
- **Can you describe what modulations would be appropriate for a power limited and a bandwidth limited channel?**
- **Can you describe two major techniques to controll errors on the satellite channel?**
- **Can you identify the three major multiple-access schemes and describe the major advantage of each?**
- **Can you list the major requirements drivers for a satellite communication subsystem**

Communications Task

3- 4

- **Deliver information from source to destination reliably**
- **Reliably**
  - **Availability**
  - **Signal Quality**

Availability

- **Solar Outage**
- **Eclipse**
- **Excess atmospheric attenuation/noise**
  - **Atmospheric gases**
  - **Rain**
  - **Clouds**
  - **Dust**
  - **Vegetation**
- **Equipment reliability**

- **Typical Availability - 99.7 % to 99.9 %**
  - **99.7 % - 27 hours/year outage**
  - **99.9% - 9 hours/year outage**

Signal Quality

- **Analog - SNR**
  - **Voice - 30 dB**
  - **Video - 50 dB**
- **Digital - Probability of bit error**
  - **Voice - $P_b < 10^{-5}$**
  - **Compressed Video - $P_b < 10^{-10}$**
- **P_b related to SNR**
  - **Modulation**
  - **Coding**

Link Budget

Link Budget

Power in dB W	Required transmit power
- Loses in dB	Transmission losses
S in dB W	Required received power
- N in dB W	Receiver noise power
SNR in dB	Required for system performance

Losses

Losses

Transmitter losses

Transmit antenna pointing loss

Free-space path loss

Excess propagation Loss

Polarization loss

Receive antenna pointing loss

Receiver losses

Gains

Transmit antenna gain

Receive antenna gain

Power Flux Density

$F_o = \frac{P_t}{4\pi R^2}$	W/m^2	(Isotropic power-flux-density)
$G_t = \frac{P_d}{P_t}$		(Antenna gain)
$P_d = G_t P_t$	W	(Directive power)
$F = \frac{G_t P_t}{4\pi R^2}$	W/m^2	(Directive power-flux-density)
$EIRP = G_t P_t$	W	(Effective isotropic radiated power)

Received Power

$P_r = F\,A_e$ W (Received power)

$$P_r = \frac{P_t\,G_t\,A_e}{4\pi R^2}$$

$G_r = \dfrac{4\pi A_e}{\lambda^2}$ (Receive antenna gain)

$P_r = P_t G_t\,G_r \left[\dfrac{\lambda}{4\pi R}\right]^2$ (Received power)

Antenna Gain

$$G = \frac{4\pi A_e}{\lambda^2}$$

$A_e = \eta A$ **(Aperture efficiency)**

$A = \eta \left[\frac{D}{2} \right]^2$ **(Circular aperture)**

$$G = 4\pi \frac{f^2}{c^2} \pi \eta \left[\frac{D}{2} \right]^2 = \eta \frac{\pi^2}{c^2} f^2 D^2$$

$$G = 20.4 + 10 \operatorname{Log}(n) + 20 \operatorname{Log}(f) + 20 \operatorname{Log}(D)$$

f in GHz
D in meters

Free Space Path Loss

$G_p = \left[\frac{\lambda}{4\pi R}\right]^2$ (Free space path loss)

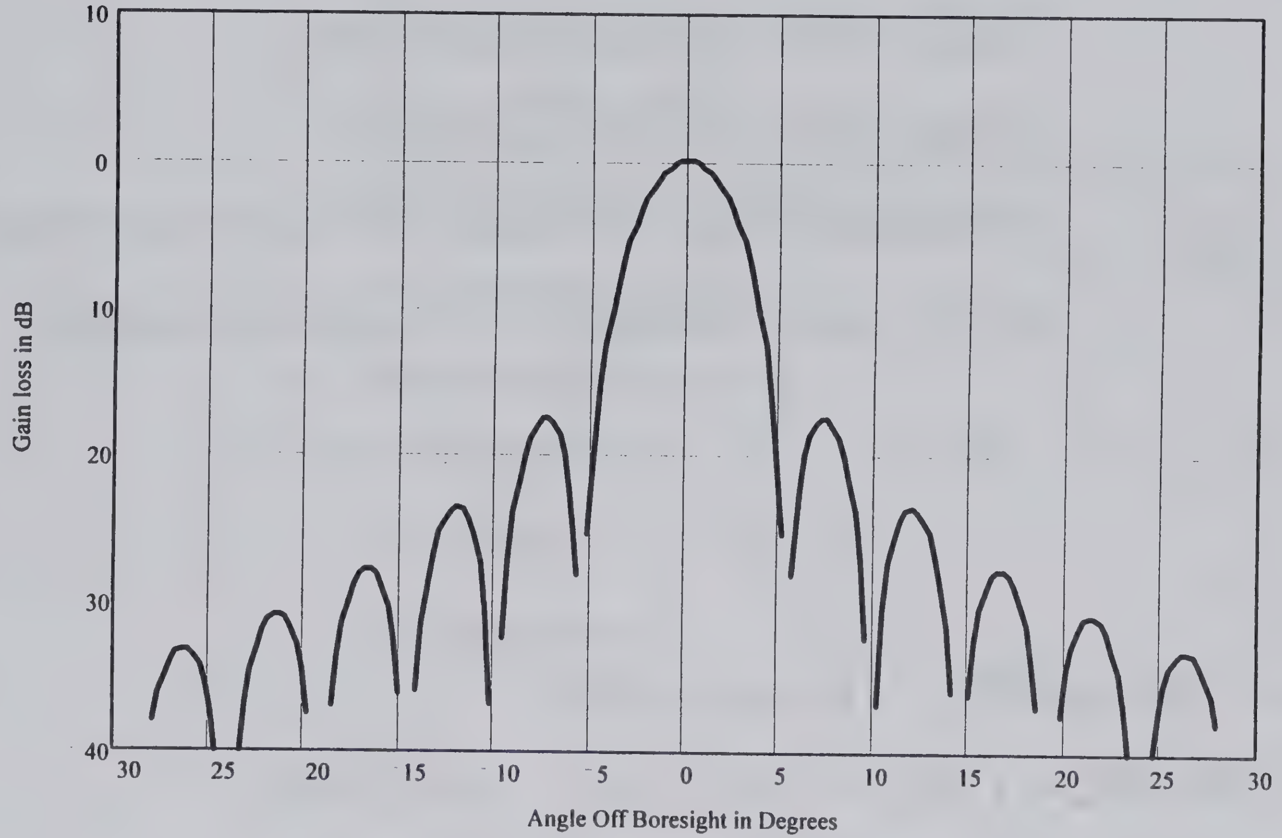
$f\lambda = c$ ($c = 3x10^8$ m/s)

$G_p = \left[\frac{c}{4\pi fR}\right]^2$

$G_p = -92.44 - 20\ \text{Log}(f) - 20\ \text{Log}(R)$

f in GHz
R in km

Antenna Pattern



Beam Pattern

Polarization Loss

R1	**(Axial ratio, transmit antenna)**
R2	**(Axial ratio, receive antenna)**
θ	**(Rotation angle between transmit and receive)**
n	**(= +1, same sense; = -1, opposite sense)**

$$\mathrm{Eff} = \frac{1}{2}\cdot\left|1 + \frac{\left(1 - \mathrm{R1}^2\right)\cdot\left(1 - \mathrm{R2}^2\right)\cdot\cos(2\cdot\theta) + 4\cdot n\cdot \mathrm{R1}\cdot \mathrm{R2}}{\left(1 + \mathrm{R1}^2\right)\cdot\left(1 + \mathrm{R2}^2\right)}\right|$$

Loss = 10 Log(Eff)   (Loss in dB)

R1 = 1 dB, R2 = 1 dB, θ = 90°, Loss = 0.057 dB

R1 = 20 dB, R2 = 20 dB, θ = 10°, Loss = 0.13 dB

Excess Propagation Loss

- **Atmospheric gas attenuation**
- **Rain attenuation**
- **Atmospheric fading**
- **Ionospheric fading**
- **Attenuation due to**
  - **Clouds**
  - **Dust**
  - **Vegetation**

Atmospheric Gas Attenuation

- **Major factors**
    - **Oxygen**
    - **Water vapor**
- **Analytic model**

  ITU-R (CCIR) Report 719-1, Attenuation by Atmospheric Gases
- **Also dependent on**
    - **Elevation angle**

      $$A = \frac{A_z}{\sin(\theta)} \qquad \theta > 10^\circ$$
    - **Altitude**

Zenith Attenuation Atmospheric Gases

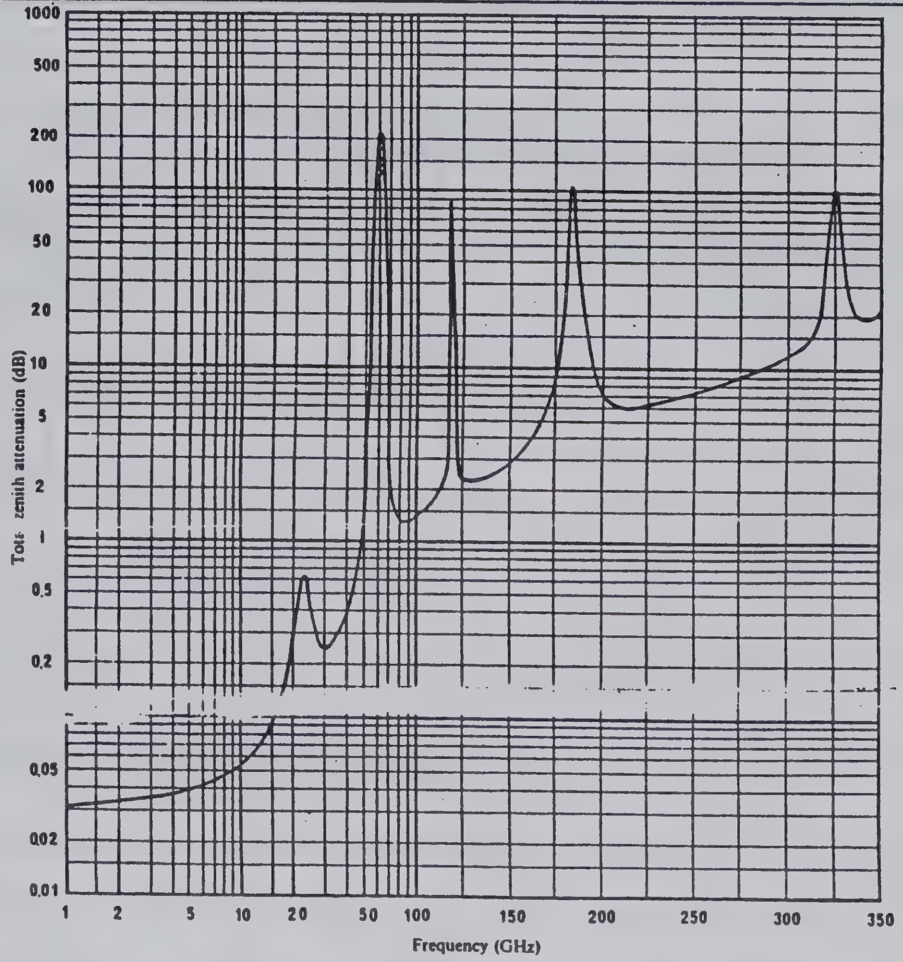


FIGURE 4 – *Total zenith attenuation*

Pressure : 1 atm
Temperature : 20° C
Water vapour : 7.5 g/m³
at ground level

Water Vapor Density

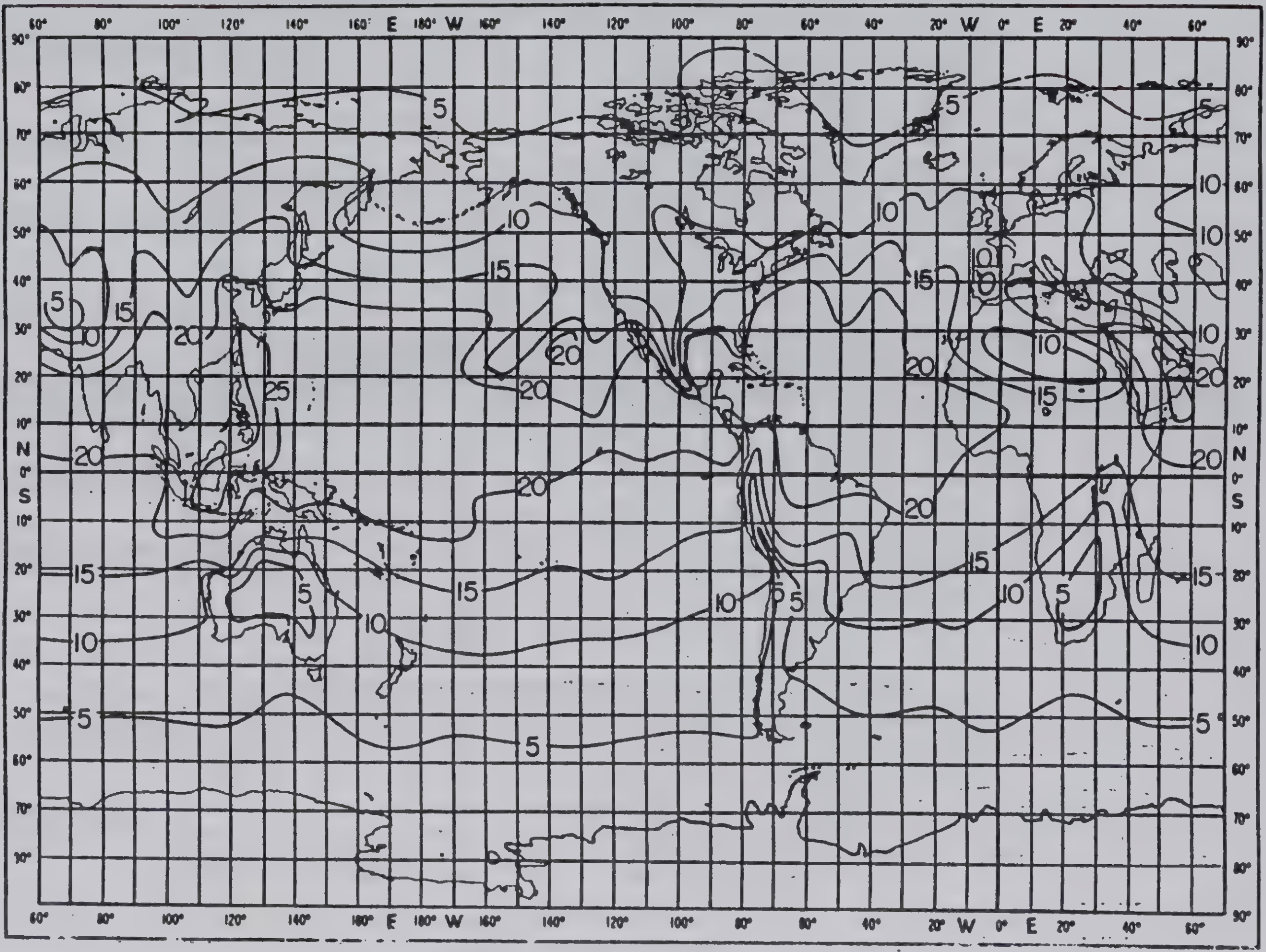

60° 80° 100° 120° 140° 160° E 180° W 160° 140° 120° 100° 80° 60° 40° 20° W 0° E 20° 40° 60°
90° 80° 70° 60° 50° 40° 30° 20° 10° N 0° S 10° 20° 30° 40° 50° 60° 70° 80° 90°
5
10
15
20
25

FIGURE 10 – *Water vapour concentration (g/m³), August*

Rain Attenuation

- Major factors
  - Frequency
  - Rain Rate
    - – Location
    - – Availability (percent outage)
  - Rain path length
    - – Elevation Angle
    - – Altitude
- Analytic Model for prediction
  - ITU-R (CCIR) Report 721-1, Attenuation by Hydrometers, in Particular Precipitation, and Other Atmospheric Particles
  - ITU-R (CCIR) Report 563-2, Radiometeorological Data

Specific Attenuation Due to Rain

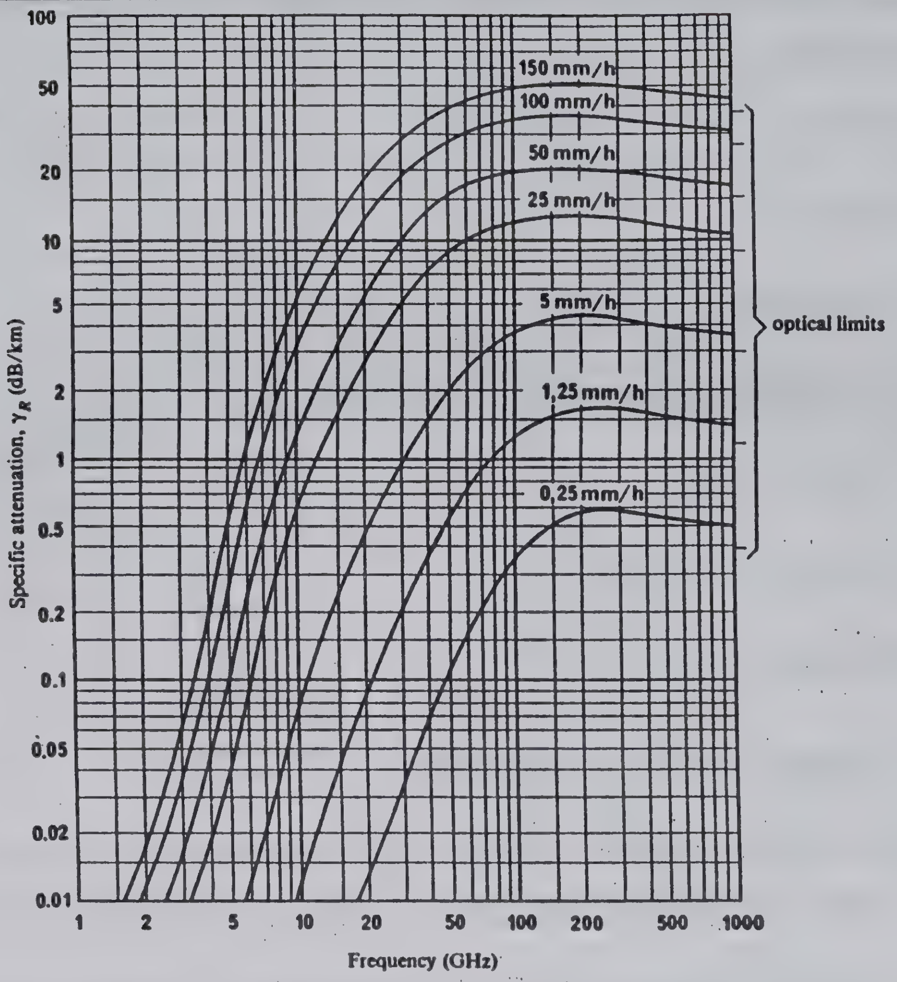


FIGURE 1 – *Specific attenuation γ_R due to rain*

Rain Rate Vs Availability

TABLE I – *Rain climatic zones*

. Rainfall intensity exceeded (mm/h) (Reference to Figs. 11 to 13)

Percentage of time (%)	A	B	C	D	E	F	G	H	J	K	L	M	N	P
1.0	-	1	-	3	1	2	-	-	-	2	-	4	5	12
0.3	1	2	3	5	3	4	7	4	13	6	7	11	15	34
0.1	2	3	5	8	6	8	12	10	20	12	15	22	35	65
0.03	5	6	9	13	12	15	20	18	28	23	33	40	65	105
0.01	8	12	15	19	22	28	30	32	35	42	60	63	95	145
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	250

Rain Regions

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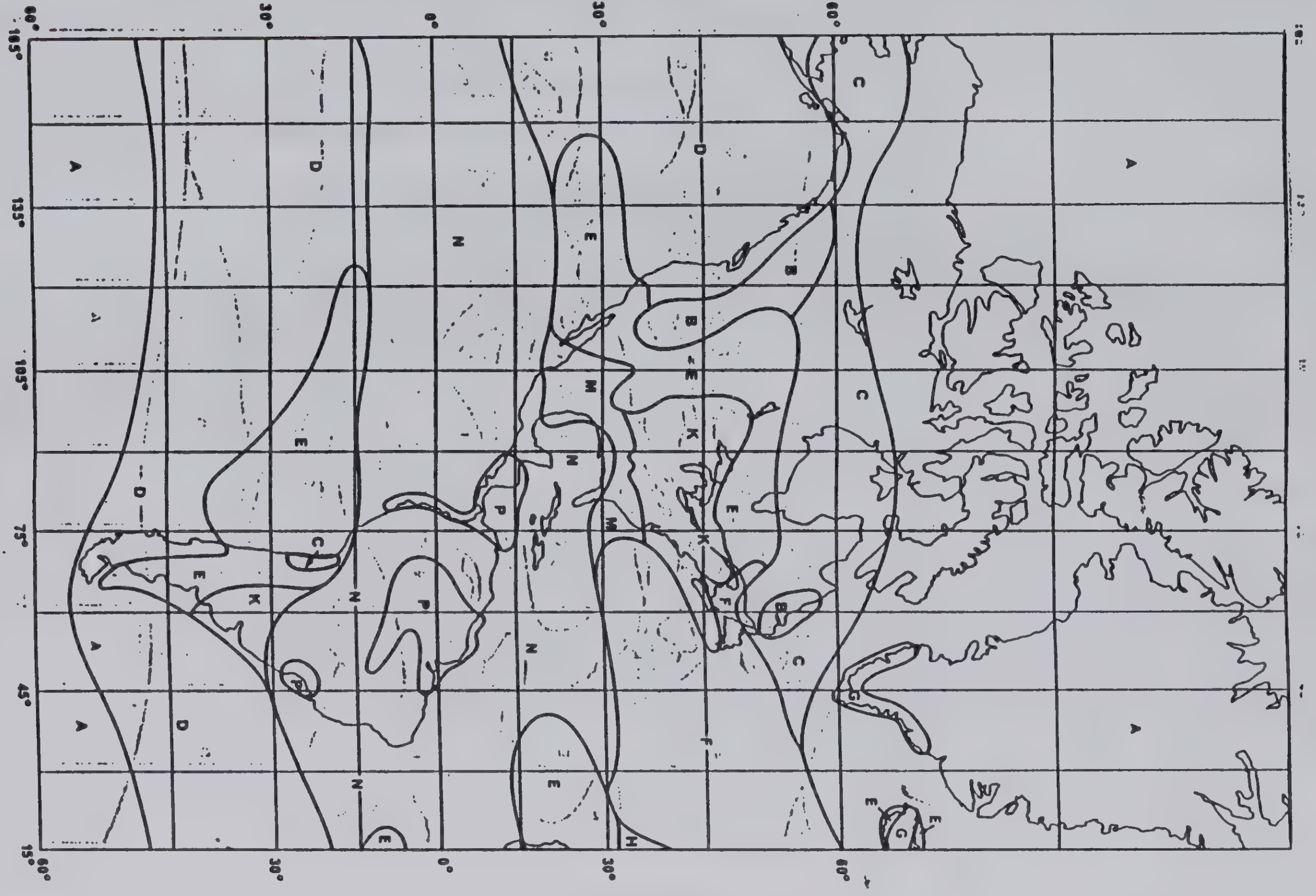

FIGURE 11
(see Table I)

Atmospheric Scintillation

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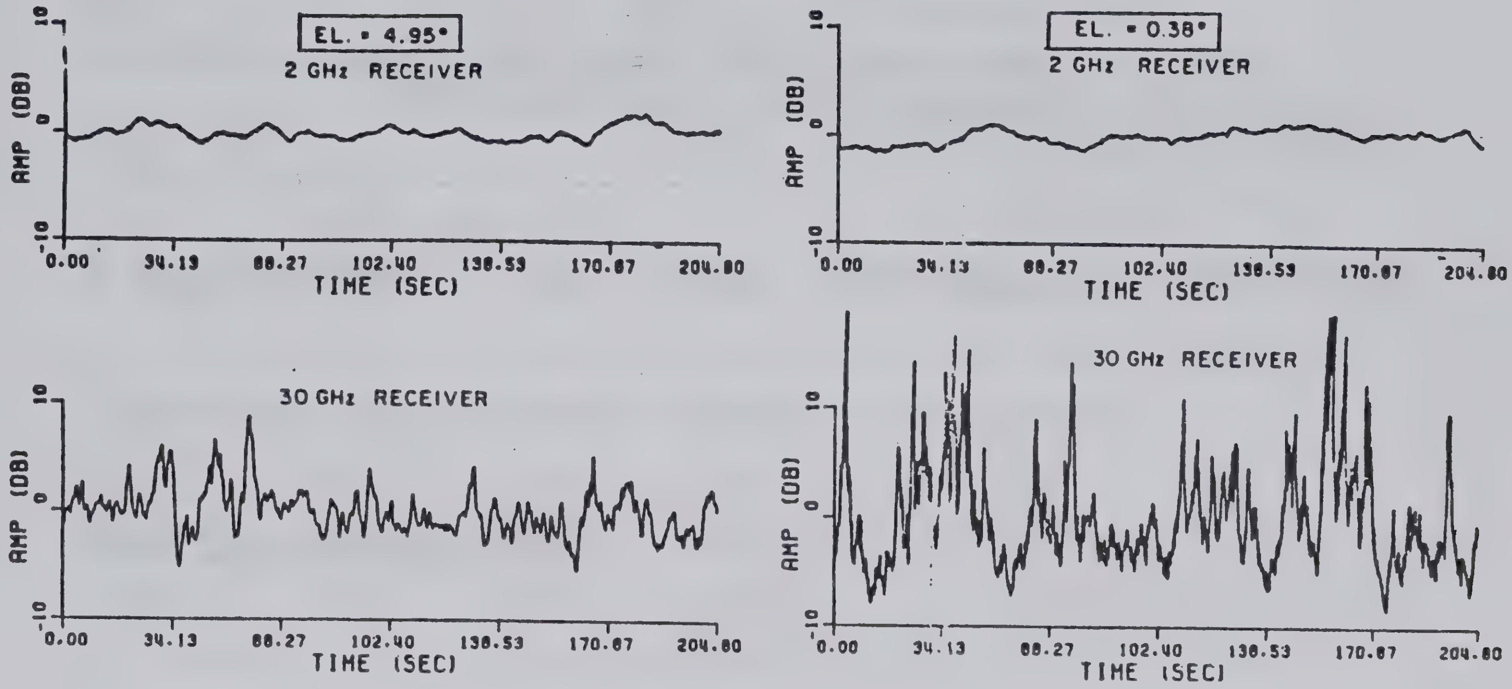


(a) (b)

Fig. 25. Amplitude scintillation measurements at and 30 GHz, made with the ATS-6 satellite at Columbus, OH, at elevation angles of (a) 4.95° and (b) 0.38°.

Ionospheric Scintillation

Table 9.3 Distribution of Mid-Latitude Fade Depths in dB due to Ionospheric Scintillation (CCIR, 1982).

Percent of Time	Frequency (MHz)			
Exceeded	100	200	500	1000
1.0	15.9	1.5	0.2	0.1
0.5	9.3	2.3	0.4	0.1
0.2	16.6	4.2	0.7	0.2
0.1	25.0	6.2	1.0	0.3

Noise

$N_\beta = k\,T\,B$	W	(Noise power)
$N_o = kT$	W/Hz	(Noise power density)
$k = 1.38 \times 10^{-23}$	J/°K	(Boltzmann's constant)

T is noise temperature of source in kelvins

B is bandwidth in Hz

Noise Sources

Background noise (atmosphere and galaxy)

Thermal noise in receiver and antenna

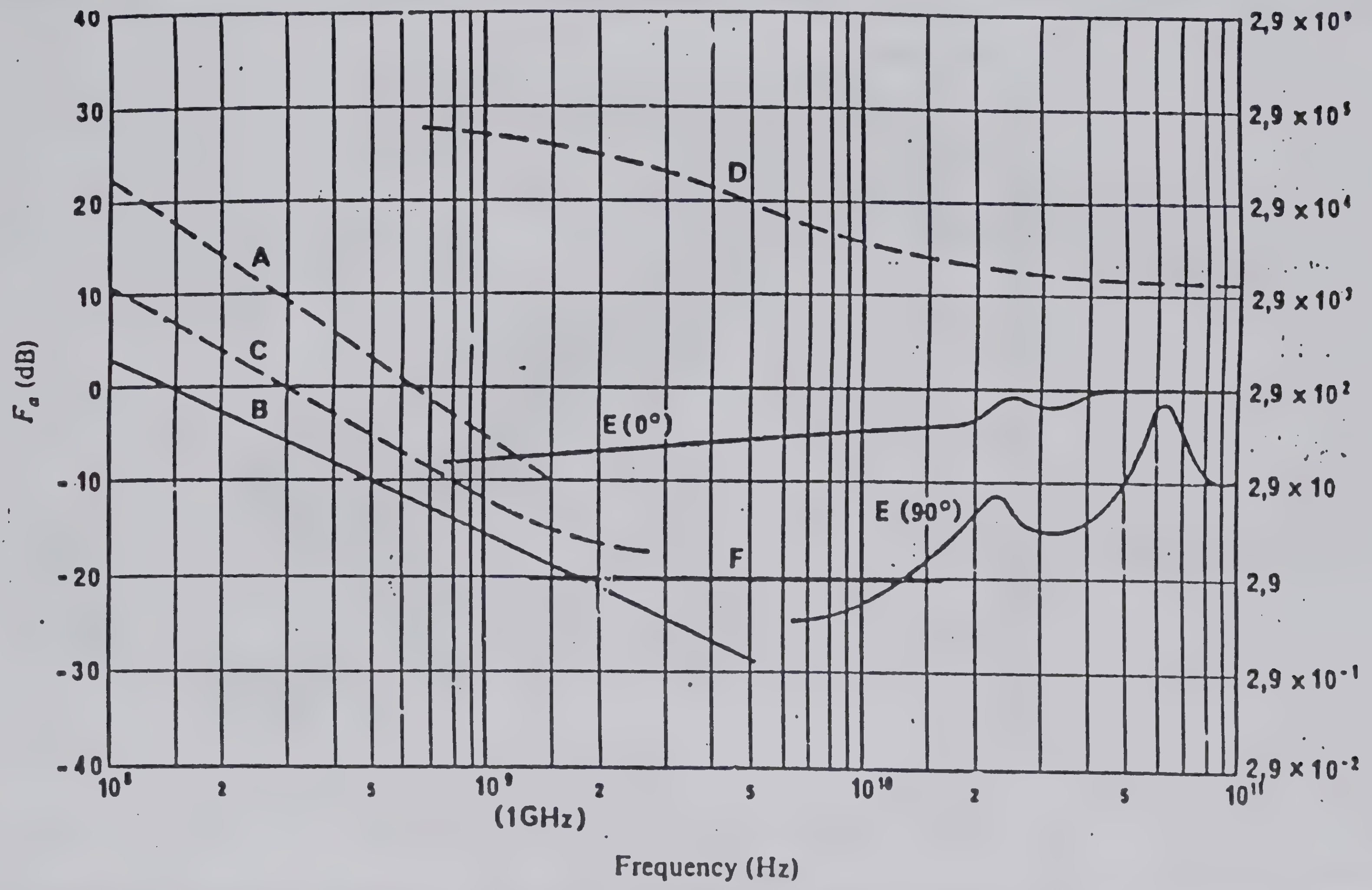
Attenuation induced noise

- **Wave guide losses**
- **Atmospheric gas attenuation**
- **Rain attenuation**

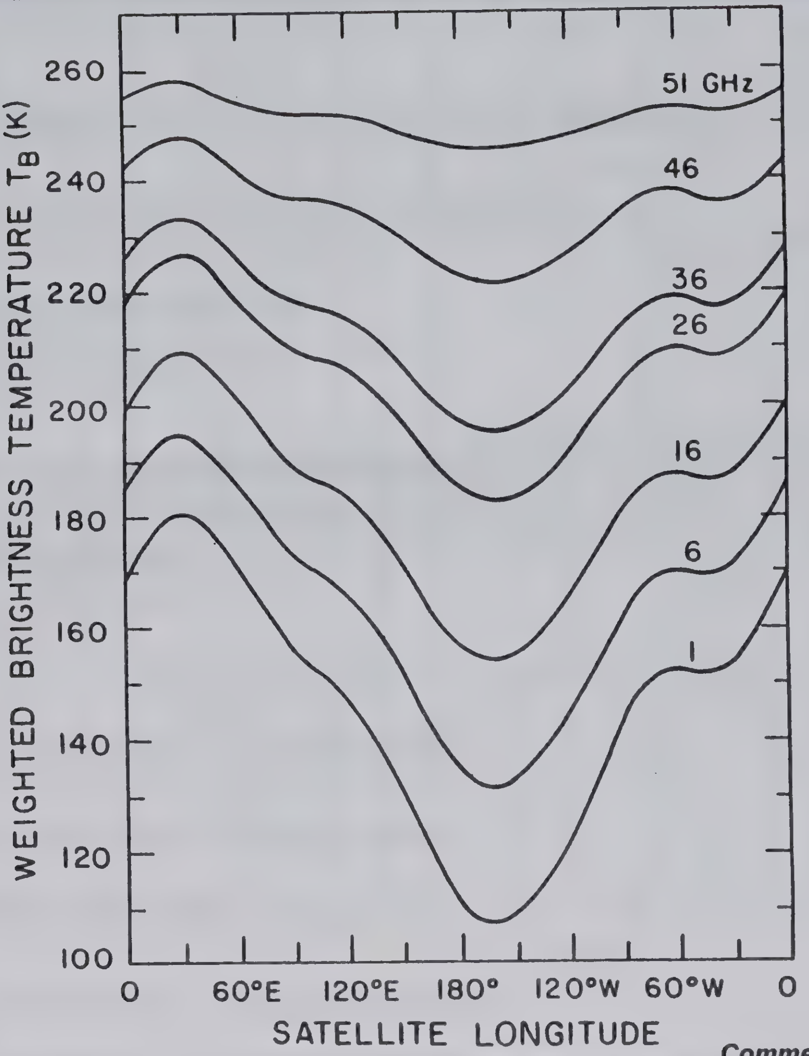
Interference

- **Adjacent channel interference**
- **Adjacent satellite interference**
- **Intermodulation interference**
- **Cross-polarization interference**

Background Temperature
Sky



Background Temperature
Earth



Antenna Temperature

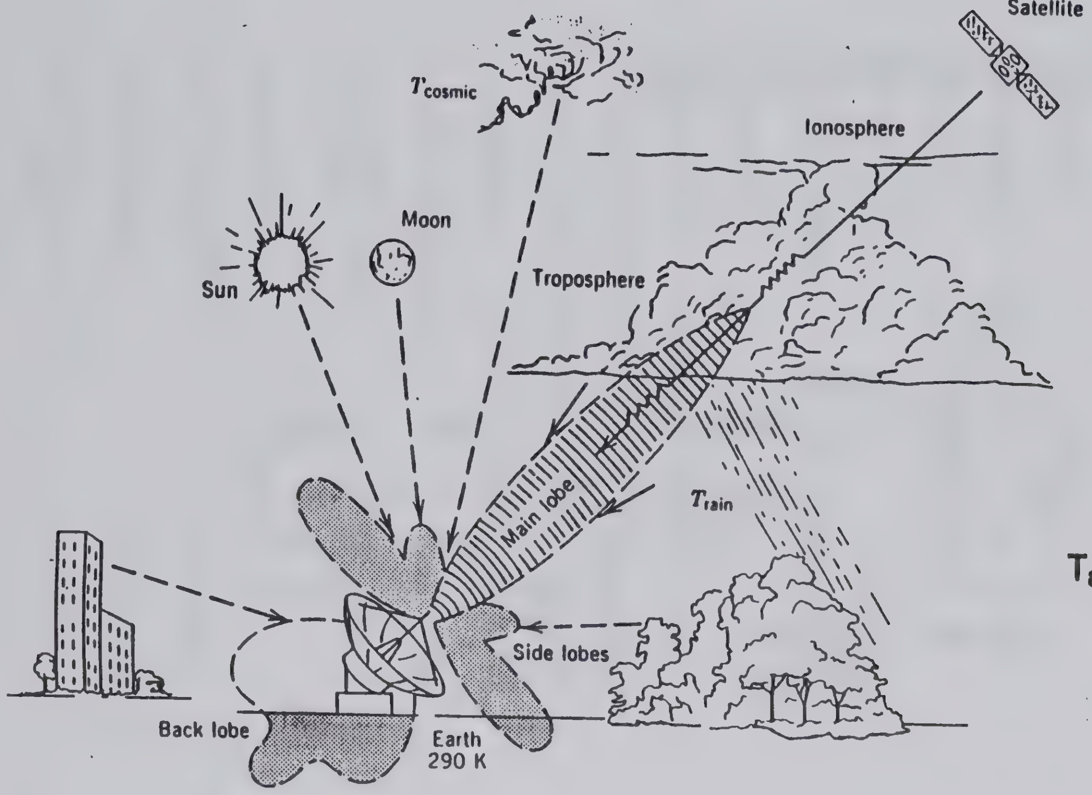
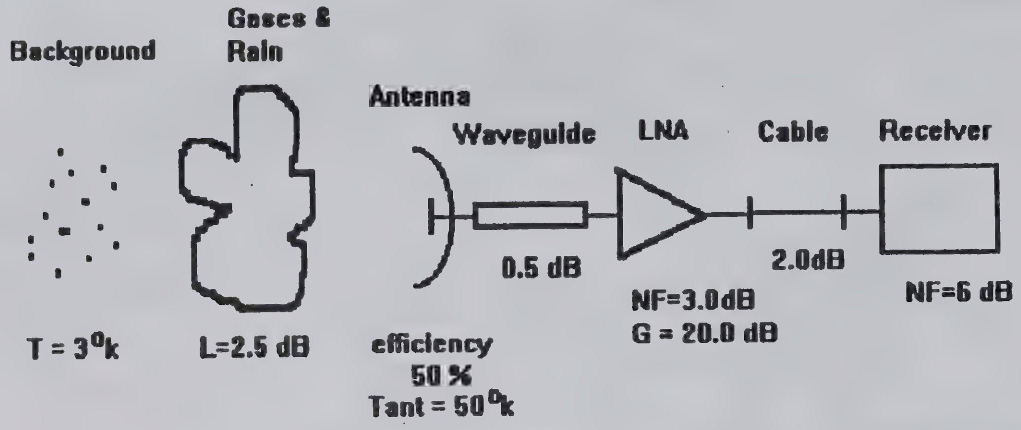


FIGURE 3.104 Antenna noise temperature pickup.

$$T_a = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} T(\theta,\phi)\, G(\theta,\phi)\, \sin(\theta)\, d\theta\, d\phi$$

Noise Example

Assume Ku-band system, 12 GHz



Noise Example (cont)

Noise Power example calculation

$\mathrm{Tback} := 3.0$

$\mathrm{LadB} := 2.5 \qquad \mathrm{La} := 10^{0.1\cdot \mathrm{LadB}} \qquad \mathrm{La} = 1.778$

$\mathrm{To} := 290$

$\mathrm{Tm} := 1.12\cdot \mathrm{To} - 50 \qquad \mathrm{Tm} = 274.8$

$\mathrm{Tsky} := \dfrac{\mathrm{Tback}}{\mathrm{La}} + \mathrm{Tm}\cdot\dfrac{\mathrm{La} - 1}{\mathrm{La}} \qquad \mathrm{Tsky} = 121.956$

$\mathrm{Tant} := 50$

$\mathrm{Eff} := 0.5$

$\mathrm{T1} := \mathrm{Tsky}\cdot \mathrm{Eff} + \mathrm{Tant} \qquad \mathrm{T1} = 110.978$

$\mathrm{LwdB} := 0.5 \qquad \mathrm{Lw} := 10^{0.1\cdot \mathrm{LwdB}} \qquad \mathrm{Lw} = 1.122$

$\mathrm{Twave} := \mathrm{To}\cdot(\mathrm{Lw} - 1) \qquad \mathrm{Twave} = 35.385$

$\mathrm{T2} := \dfrac{\mathrm{T1}}{\mathrm{Lw}} + \mathrm{Twave} \qquad \mathrm{T2} = 134.294$

$\mathrm{NFlna} := 3.0$

$\mathrm{GlnadB} := 20.0 \qquad \mathrm{Glna} := 10^{0.1\cdot \mathrm{GlnadB}} \qquad \mathrm{Glna} = 100$

$\mathrm{Tlna} := \mathrm{To}\cdot\left(10^{0.1\cdot \mathrm{NFlna}} - 1\right) \qquad \mathrm{Tlna} = 288.626$

$\mathrm{T3} := (\mathrm{T2} + \mathrm{Tlna})\cdot 10^{0.1\cdot \mathrm{GlnadB}} \qquad \mathrm{T3} = 4.229\cdot 10^{4}$

$\mathrm{LcabledB} := 2.0 \qquad \mathrm{Lcable} := 10^{0.1\cdot \mathrm{LcabledB}} \qquad \mathrm{Lcable} = 1.585$

$\mathrm{Tcable} := \mathrm{To}\cdot(\mathrm{Lcable} - 1) \qquad \mathrm{Tcable} = 169.619$

$\mathrm{T4} := \dfrac{\mathrm{T3}}{\mathrm{Lcable}} + \mathrm{Tcable} \qquad \mathrm{T4} = 2.685\cdot 10^{4}$

$\mathrm{NFrec} := 6.0$

$\mathrm{Trec} := \mathrm{To}\cdot\left(10^{0.1\cdot \mathrm{NFrec}} - 1\right) \qquad \mathrm{Trec} = 864.511$

$\mathrm{T5} := \mathrm{T4} + \mathrm{Trec} \qquad \mathrm{T5} = 2.772\cdot 10^{4}$

$\mathrm{Ts} := \dfrac{\mathrm{T5}}{\mathrm{Glna}}\cdot \mathrm{Lcable} \qquad \mathrm{Ts} = 439.31$

Interference

$$\frac{C}{N} = \frac{1}{\dfrac{1}{\frac{C}{N_u}} + \dfrac{1}{\frac{C}{N_d}} + \dfrac{1}{\frac{C}{N_{im}}} + \dfrac{1}{\frac{C}{N_{as}}} + \dfrac{1}{\frac{C}{N_{ac}}} + \dfrac{1}{\frac{C}{N_{cp}}}}$$

Add like resistors in parallel

Minimum value dominates

Example Link Budget
Uplink

	f 14.5	GHz
Pt 10·log(500)	Pt = 26.99	dBW
	Lt 1.0	dB
	dt 9.0	meters
	ηt 0.55	
Gt 20.4 10·log(ηt) 20·log(f·dt)	Gt = 60.116	dB
	Lpt 0.5	dB
EIRP Pt Lt Gt Lpt	EIRP = 85.606	dBW
	R 40600	km
Pl 92.44 20·log(f·R)	Pl = 207.838	dB
	Al 1.0	dB
	Rl 8.0	dB
Ri EIRP Pl Al Rl	Ri = 131.232	dBW
G1 20.4 20·log(f·1.13)	G1 = 44.689	dB
PFD Ri G1	PFD = 86.543	dBW/m2
	Pol 0.2	dB
	Lpr 3.0	dB
	dr 0.5	dB
	ηr 0.55	
Gr 20.4 10·log(ηr) 20·log(f·dr)	Gr = 35.01	dB
	Lr 1.0	dB
C Ri Pol Lpr Gr Lr	C = 100.422	dBW
Tsys 10·log(750)	Tsys = 28.751	dB-ok
BW 10·log(36) 60	BW = 75.563	dB-Hz
N 228.6 Tsys BW	N = 124.286	dBW
CNRu C N	CNRu = 23.864	dB

Example Link Budget
Downlink

	f 12.2	GHz
Pt 10·log(50)	Pt = 16.99	dBW
	Lt 1.0	dB
	dt 0.5	meters
	ηt 0.55	
Gt 20.4 10·log(ηt) 20·log(f·dt)	Gt = 33.51	dB
	Lpt 3.0	dB
EIRP Pt Lt + Gt Lpt	EIRP = 46.5	dBW
	R 40600	km
Pl 92.44 20·log(f·R)	Pl = 206.338	dB
	Al 1.0	dB
	Rl 5.0	dB
Ri EIRP + Pl + Al Rl	Ri = 165.838	dBW
G1 20.4 20·log(f·1.13)	G1 = 43.189	dB
PFD Ri G1	PFD = 122.649	dBW/m2
	Pol 0.2	dB
	Lpr 0.5	dB
	dr 9.0	dB
	ηr 0.55	
Gr 20.4 10·log(ηr) + 20·log(f·dr)	Gr = 58.616	dB
	Lr 1.0	dB
C Ri Pol Lpr Gr Lr	C = 108.922	dBW
Tsys 10·log(480)	Tsys = 26.812	dB-ok
BW 10·log(36) 60	BW = 75.563	dB-Hz
N 228.6 Tsys BW	N = 126.225	dBW
CNRd C N	CNRd = 17.302	dB

Example Link Budget Overall

CNRu = 23.864 dB

CNRd = 17.302 dB

CNRi 30 dB

CNRas 20 dB

CNRpol 30 dB

$$\mathrm{CNRr} \quad \frac{1}{\left(\frac{1}{10^{.1\cdot \mathrm{CNRu}}}\right) + \frac{1}{10^{.1\cdot \mathrm{CNRd}}} + \frac{1}{10^{.1\cdot \mathrm{CNRi}}} + \frac{1}{10^{.1\cdot \mathrm{CNRas}}} + \frac{1}{10^{.1\cdot \mathrm{CNRpol}}}}$$

$$\mathrm{CNR} \quad 10\cdot\log(\mathrm{CNRr}) \qquad \mathrm{CNR} = 14.594 \ \mathrm{dB}$$

Link Budget Summary

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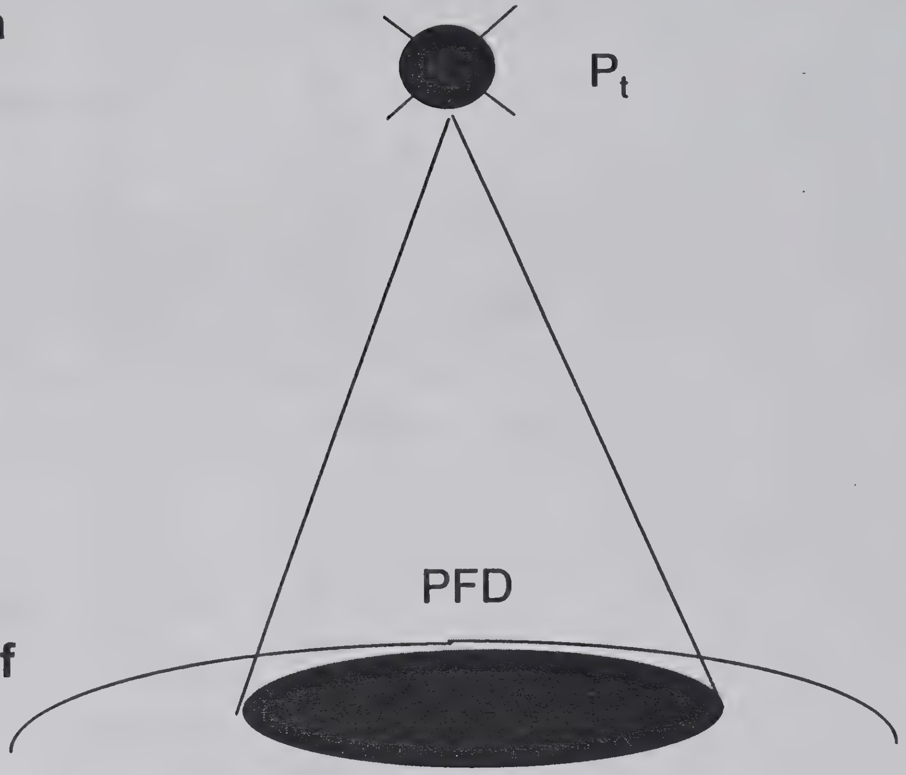
- For a given communications signal, the receiver requires a definable power level

$$P_r = S/N * N$$

- Receive antenna collects power

$$PFD = P_r/A_e$$

- Satellite power depends on PFD and coverage area
- Satellite power is approximately independent of satellite altitude



Modulation

Performance

Analog Voice - S/N = 30 dB

Analog Video - S/N = 50 dB

Digital Voice - $P_b < 10^{-5}$

Digital Video - $P_b < 10^{-9}$

Digital Data - $P_b < 10^{-6}$

- **Bit error probability may not be the proper performance metric for a given system**

Analog Modulation

FM modulation commonly used

$$\frac{S}{N} = \frac{C}{N} \; 3\,(1+\beta)\,\beta^2$$

β is the modulation index
For wideband FM, typically used, $\beta >> 1$
SNR > CNR

$\beta = 9$ (typical)
CNR = 16.15 dB   SNR = 50 dB

Digital Modulation

- **Many different modulation and coding schemes**
- **Generally, the goal is to**
  - **Minimize power (power efficiency)**
  - **Maximize throughput (bandwidth efficiency, bits/sec/Hz)**
- **Other goals may apply for different systems**
  - **Anti-jam and LPI for military communications**

Digital Modulation

$$\frac{C}{N} = \frac{E_b\, R_b}{N_o\, W}$$

R_b is data rate in bits/sec

W is bandwidth in Hz

$\frac{R_b}{W}$ is bandwidth efficiency bits/sec/Hz

Probability of bit error, P_b is related to $\left(E_b/N_o\right)$ ENERGY IN BITS / NOISE

- Modulation
- Coding

Probability of Error

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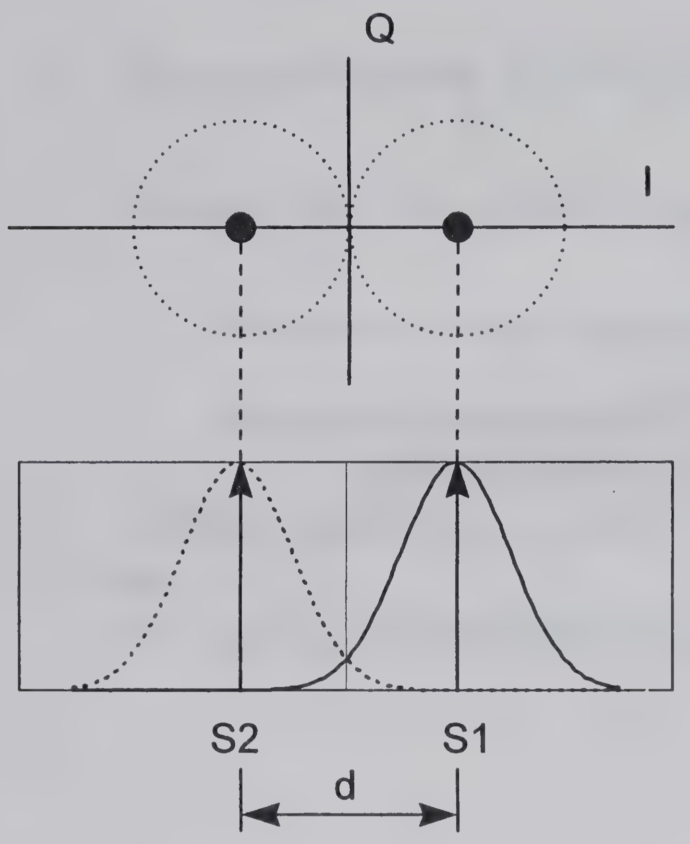


Maximum Likelihood Detector

Pe = P(s2|s1)*P(s1) + P(s1|s2)*P(s2)

$$P(s1|s2) = \frac{1}{\sqrt{2\pi}\,\sigma}\int_{d/2}^{\infty} e^{-x^2/2\sigma^2}\,dx$$

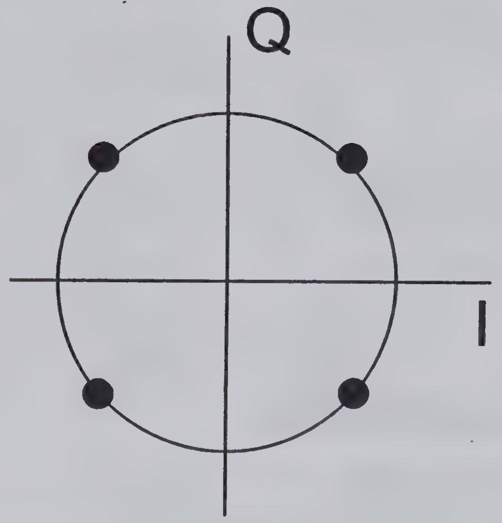
$$P(s1|s2) = \frac{1}{\sqrt{2\pi}}\int_{\frac{d}{\sqrt{No/2}}}^{\infty} e^{-\gamma^2/2}\,d\gamma$$

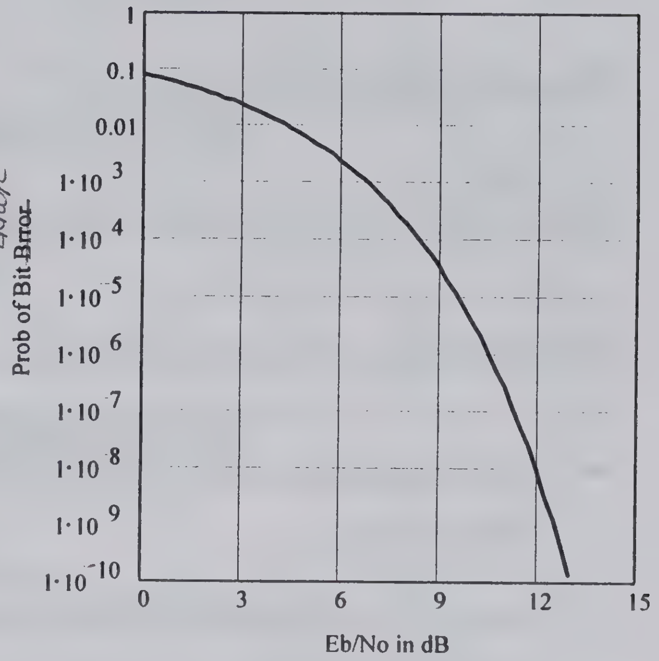
P(s1|s2) = P(s2|s1) (from symmetry)
P(s1) = P(s2) (equally likely symbols)

$$Pe = Q\left(\sqrt{\frac{2d^2}{No}}\right) = Q\left(\sqrt{\frac{2E}{No}}\right)$$

(SOFT DETECTION)

QPSK





$S(t) = I(t)\cos(\omega ct) + Q(t)\sin(\omega ct)$

Power is radius squared

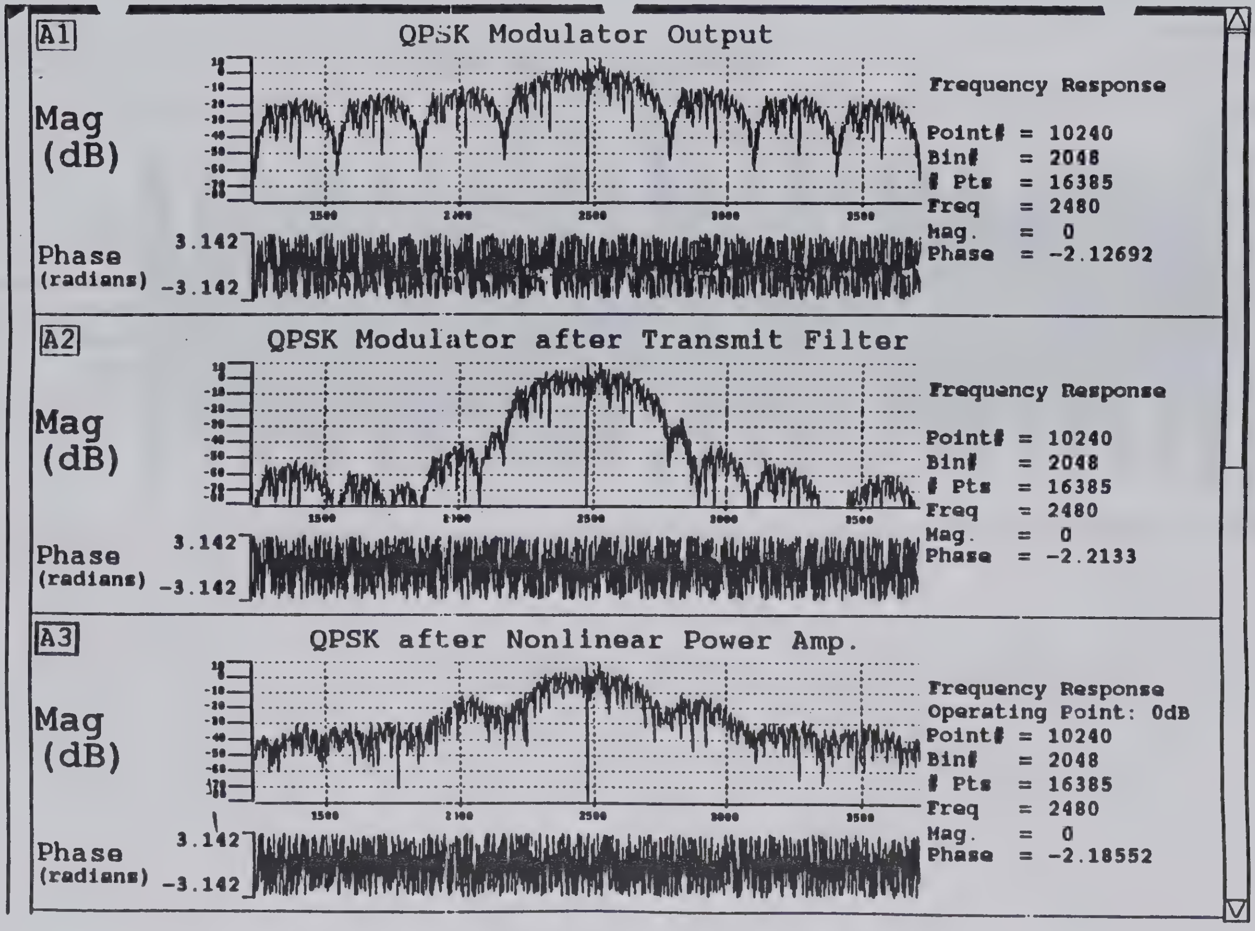
Error probability dependent on distance between constellation points

QPSK Characteristics

- **Reasonably efficient throughput (2 b/s/Hz)**
- **Reasonably low power**
- **Constant Amplitude Modulation**
- **Amplitude distortion has only moderate effect**
    - **Can operate with saturated power amplifier for higher power efficiency**
    - **Requires filtering after non-linear amplificfation (regenerates spectral sidelobes through non-linear amplifier)**

QPSK Spectral Sidelobes

3- 46



```
Frequency Response

Point# = 10240
Bin#   = 2048
# Pts  = 16385
Freq   = 2480
Mag.   =  0
Phase  = -2.12692
```

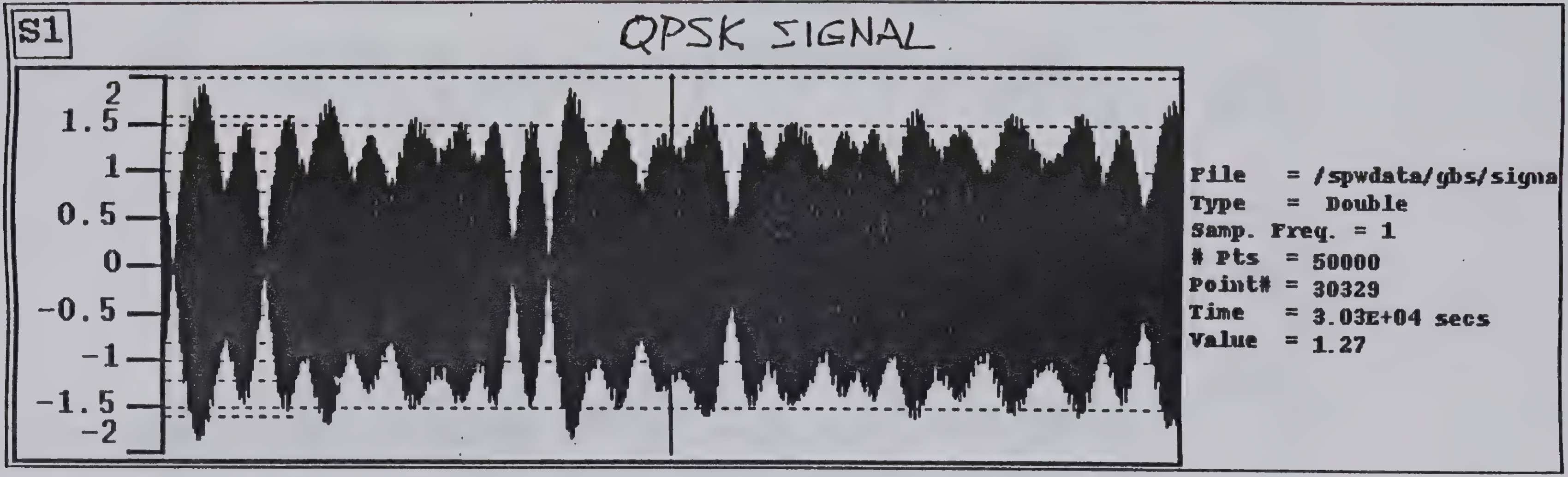
```
Frequency Response

Point# = 10240
Bin#   = 2048
# Pts  = 16385
Freq   = 2480
Mag.   =  0
Phase  = -2.2133
```

```
Frequency Response
Operating Point: 0dB
Point# = 10240
Bin#   = 2048
# Pts  = 16385
Freq   = 2480
Mag.   =  0
Phase  = -2.18552
```

Filtered QPSK

3- 47

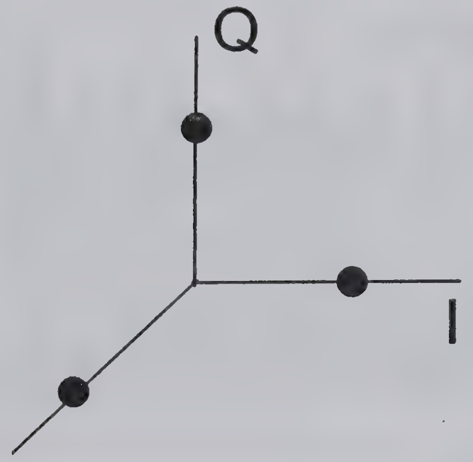


```
File   = /spwdata/gbs/signa
Type   =  Double
Samp. Freq. = 1
# Pts  = 50000
Point# = 30329
Time   = 3.03E+04 secs
Value  = 1.27
```

Other Digital Modulations

- **Power efficient**
    - **M-ary orthogonal**
- **Bandwidth efficient**
    - **M-ary PSK**
    - **QAM** QUADRATURE (AND) AMPLITUDE MODULATION
- **Spectral Control**
    - **GMSK** GAUSSIAN MEAN (OR MINIMUM) SHIFT KEYING

M-ary Orthogonal



As M increases
  - Power decreases
  - bandwidth increases

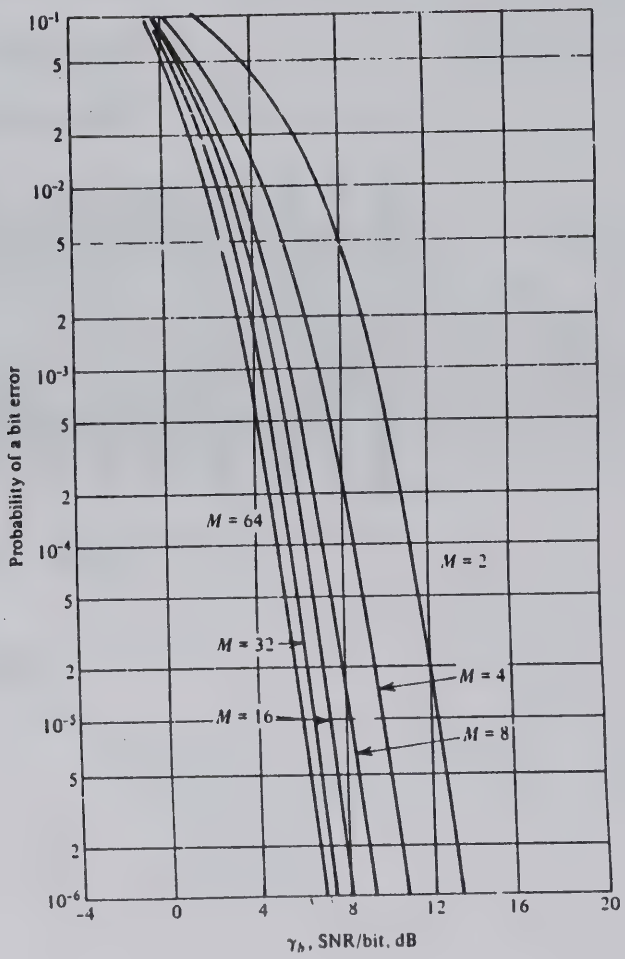
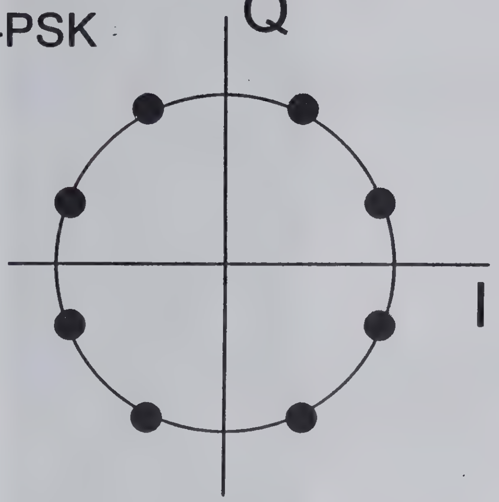
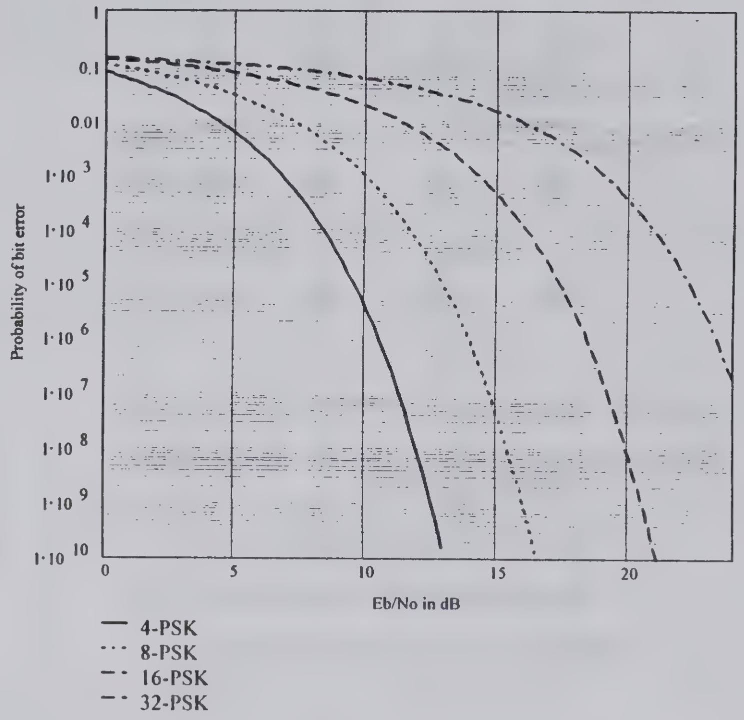


Figure 4.2.8 Probability of bit error for coherent detection of orthogonal signals.

M-PSK

8-PSK

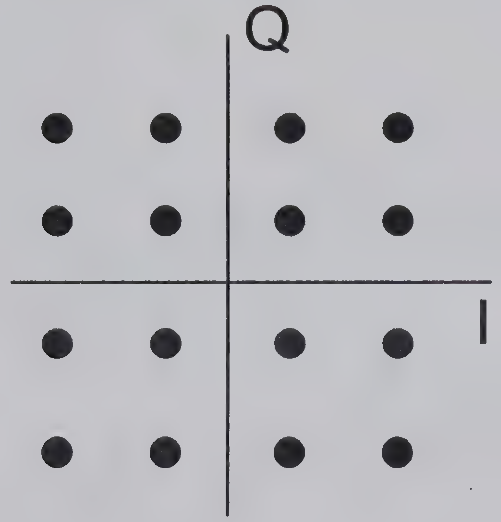


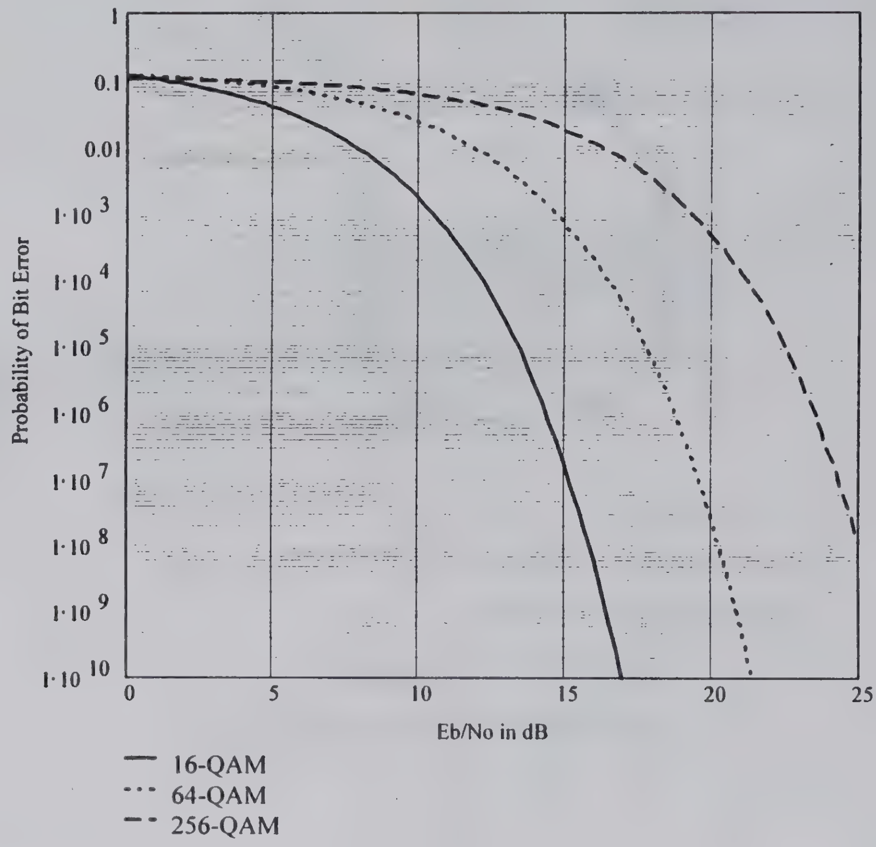


As M increases

- power increases
- bandwidth decreases

QAM





- Multi-phase
- Multi-amplitude
- Sensitive to phase and amplitude distortions

GMSK

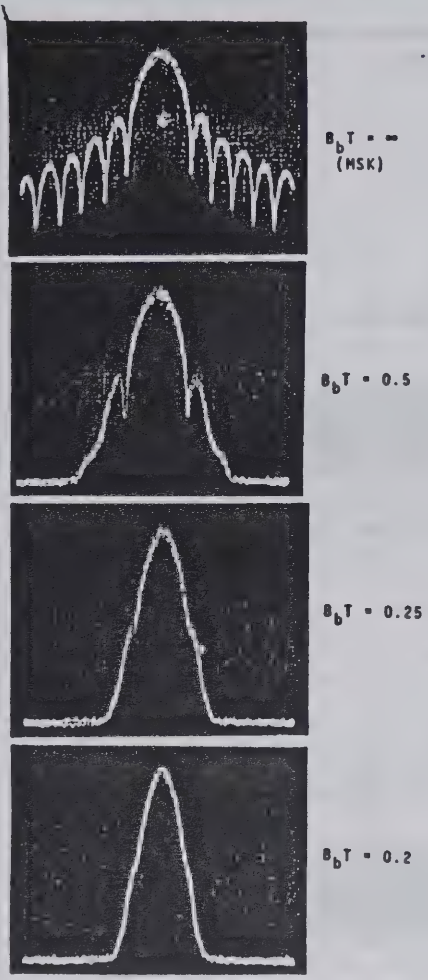


Fig. 10. Measured power spectra of GMSK (V: 10 dB/div., H: 10 kHz/div.).

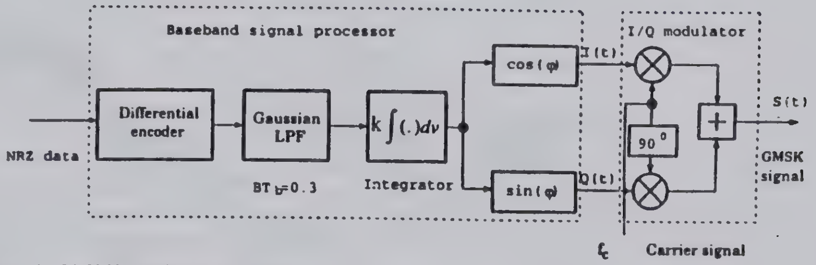


Figure 1. GMSK quadrature modulator.

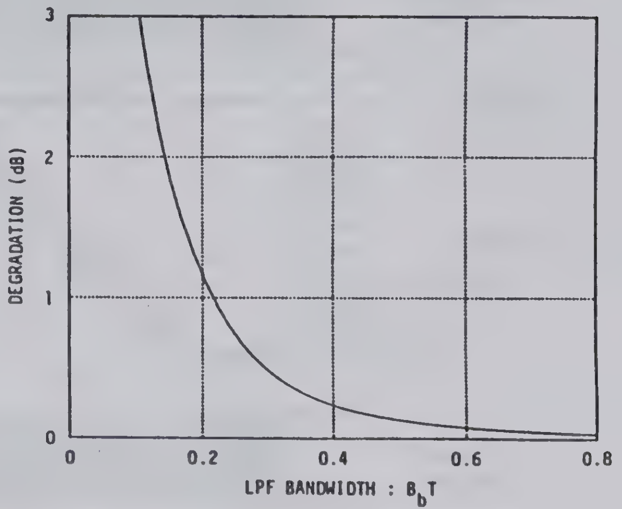
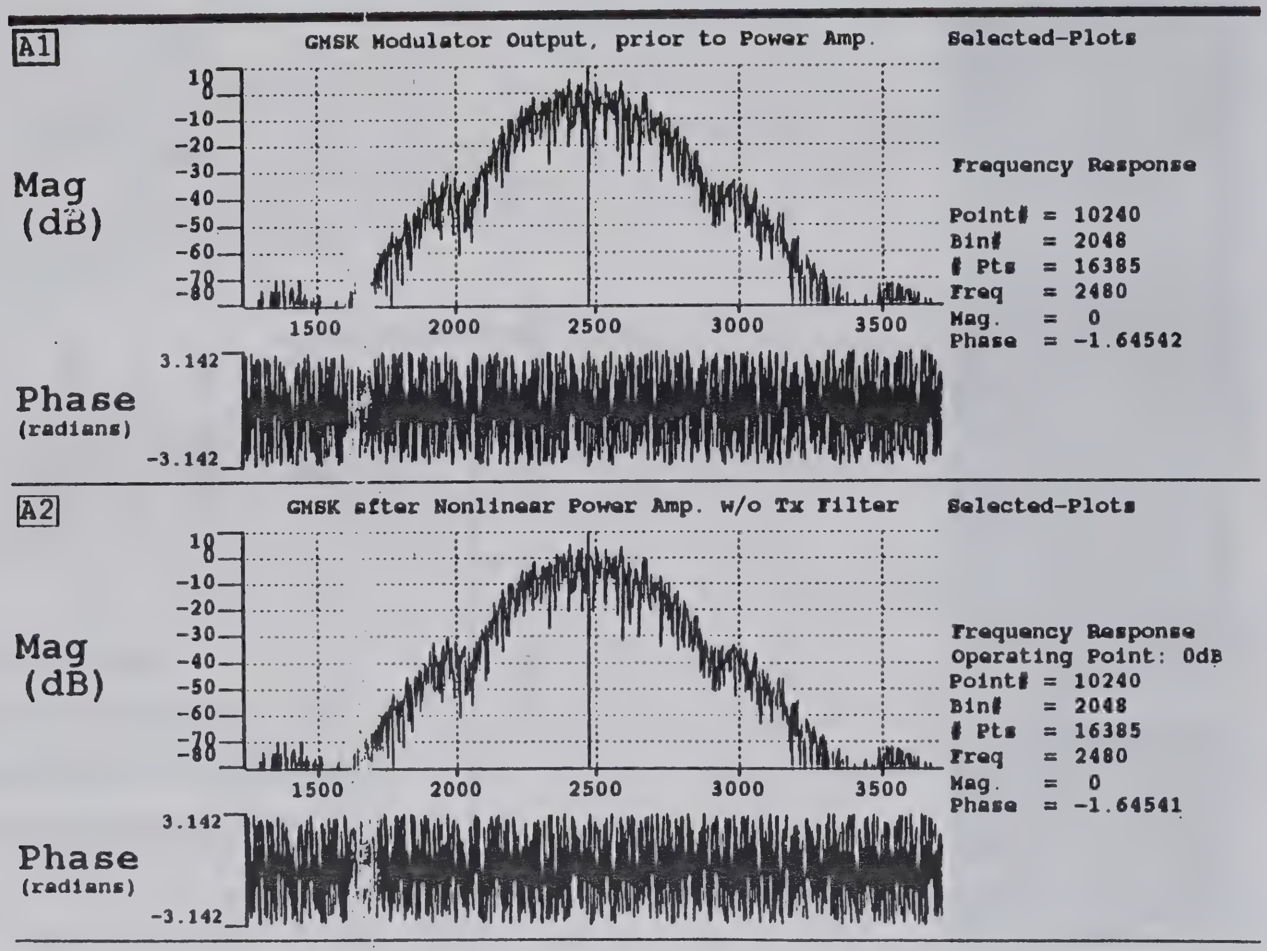


Fig. 6. Theoretical E_b/N_0 degradation of GMSK.

GMSK Sidelobes



GMSK Modulator Output, prior to Power Amp.   Selected-Plots

```
Frequency Response

Point# = 10240
Bin#   = 2048
# Pts  = 16385
Freq   = 2480
Mag.   =  0
Phase  = -1.64542
```

GMSK after Nonlinear Power Amp. w/o Tx Filter   Selected-Plots

```
Frequency Response
Operating Point: 0dB
Point# = 10240
Bin#   = 2048
# Pts  = 16385
Freq   = 2480
Mag.   =  0
Phase  = -1.64541
```

Modulation Comparison
Power and Bandwidth

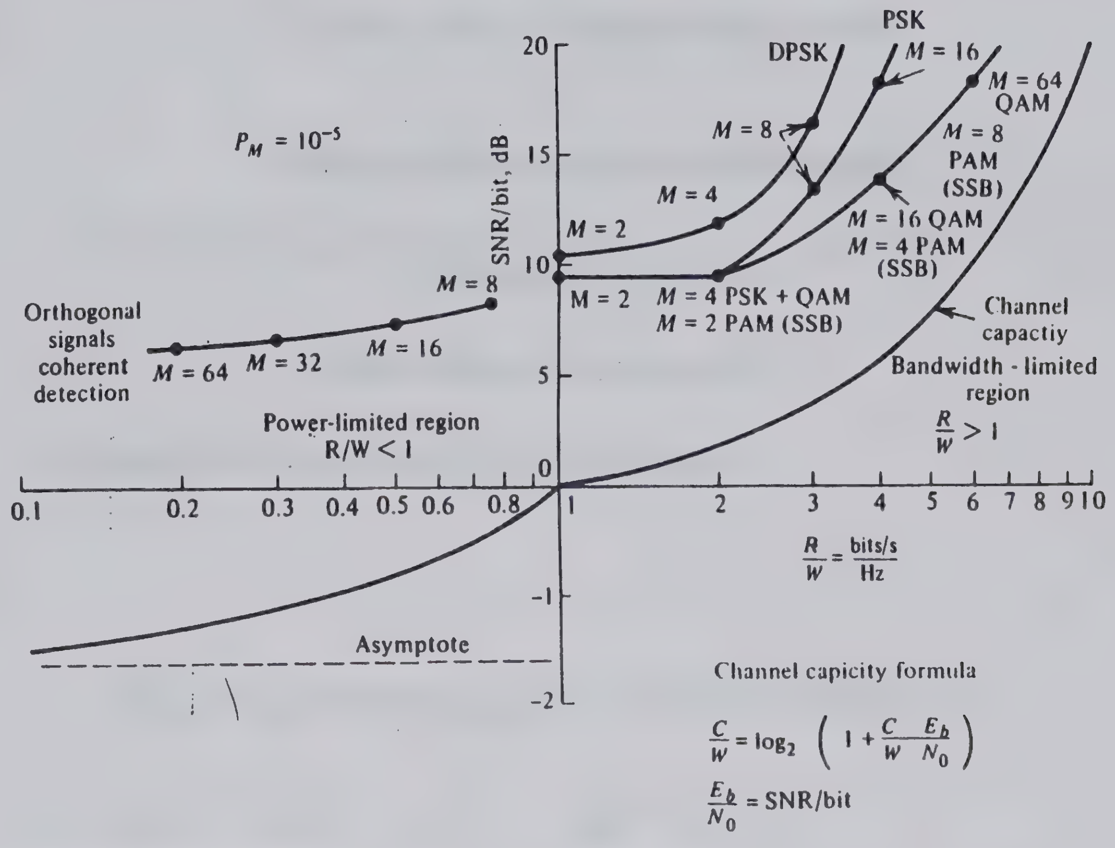


Figure 4.2.31 Comparison of several modulation methods at 10^{-5} symbol error probability.

Modulation Summary

What modulation to use??

Depends on requirements

- **Power efficiency**
- **Bandwidth efficiency**
- **Transmitter/Receiver complexity**

Performance dependent on E_b/N_o

$P_r = E_b * R_b$ POWER REQMT = ENERGY PER BIT x BIT RATE

Error Correction Coding

Error Control

- Two basic schemes used for error control
  - Automatic Repeat reQuest (ARQ)
    - Uses error detection code to determine validity of data
    - Requests retransmission if error detected
  - Forward Error Correction (FEC)
    - Uses error correction code to correct data on forward path
    - Decrease Pb for given Eb/No
    - Decrease Eb/No for given Pb
  - Both require additional bits for overhead
    - ARQ generally requires less overhead

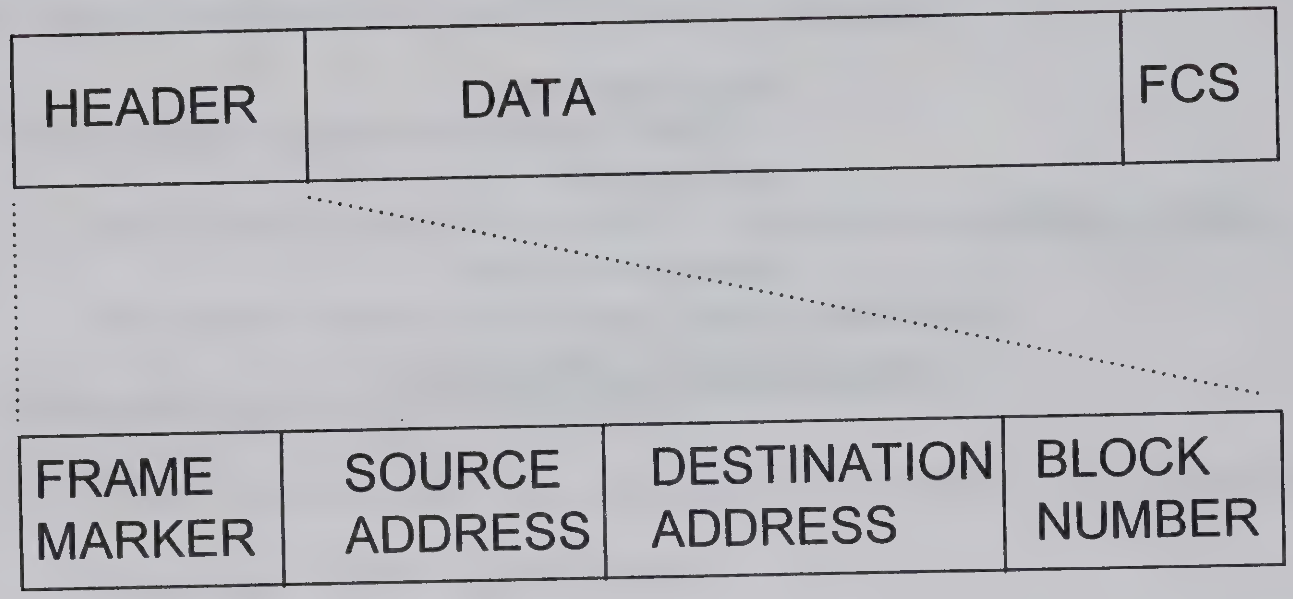
ARQ

Three basic types

- **Stop and wait**
- **Go back N**
- **Selective repeat**

Interested in efficiency

Block Format



HEADER

DATA

FCS

FRAME MARKER

SOURCE ADDRESS

DESTINATION ADDRESS

BLOCK NUMBER

FCS = Frame Check Sequence (Error detecting code)

Efficiency Factors

- **Header size in bits**
- **Data block size in bits**
- **Channel bit rate**
- **Propagation time**
- **Receiver service time (ACK turnaround time)**
- **Channel bit error probability**

Stop and Wait ARQ

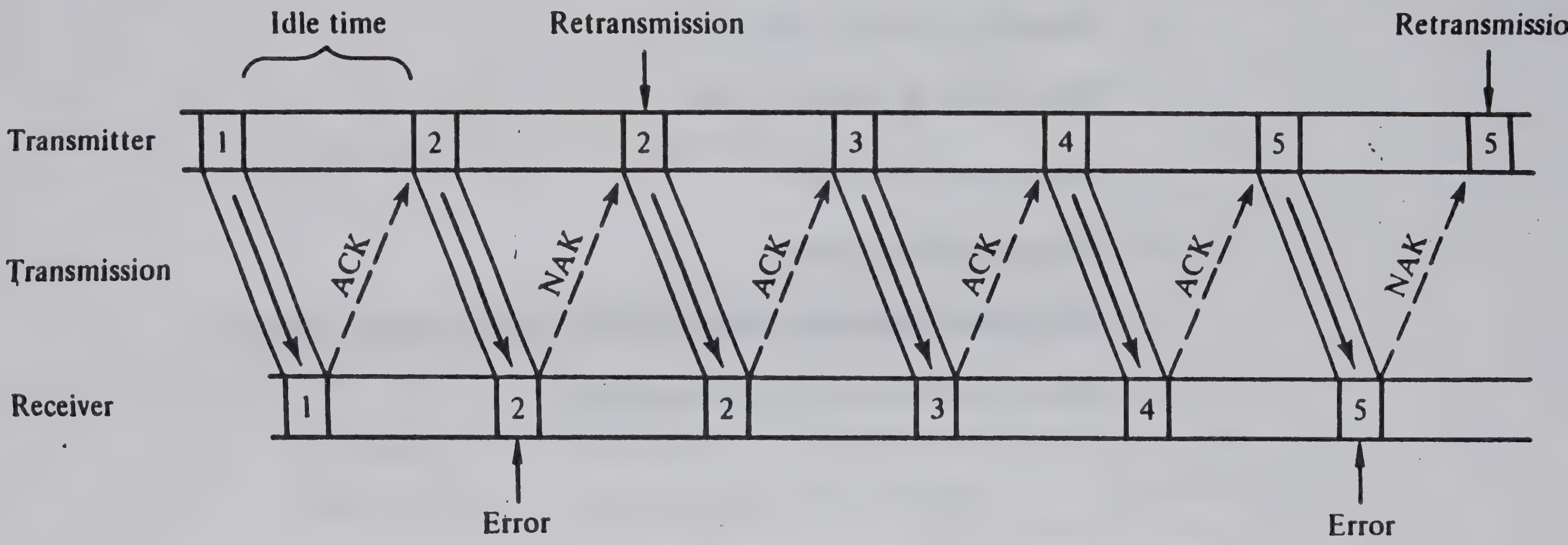


Figure 15.1 Stop-and-wait ARQ.

Go Back N ARQ

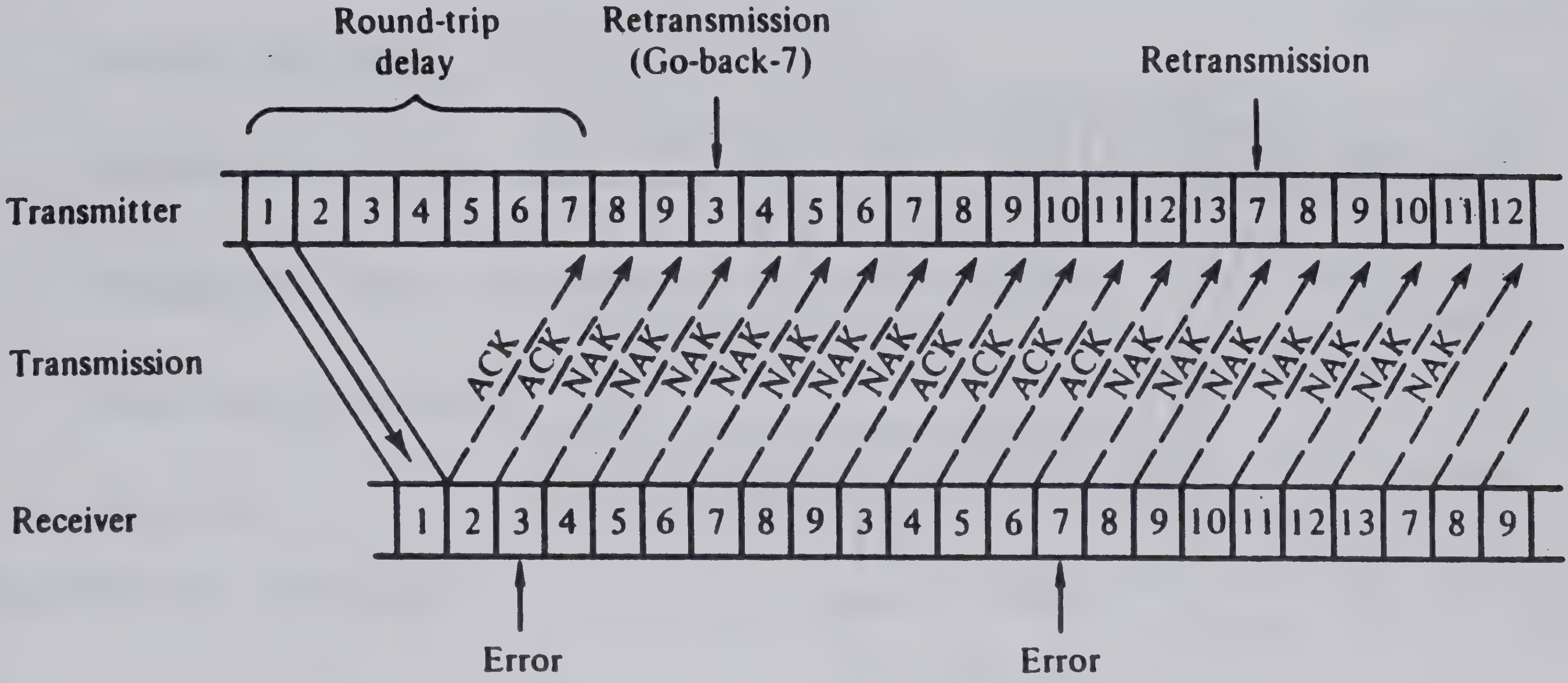


Figure 15.2 Go-back-*N* ARQ with $N = 7$.

Selective Repeat ARQ

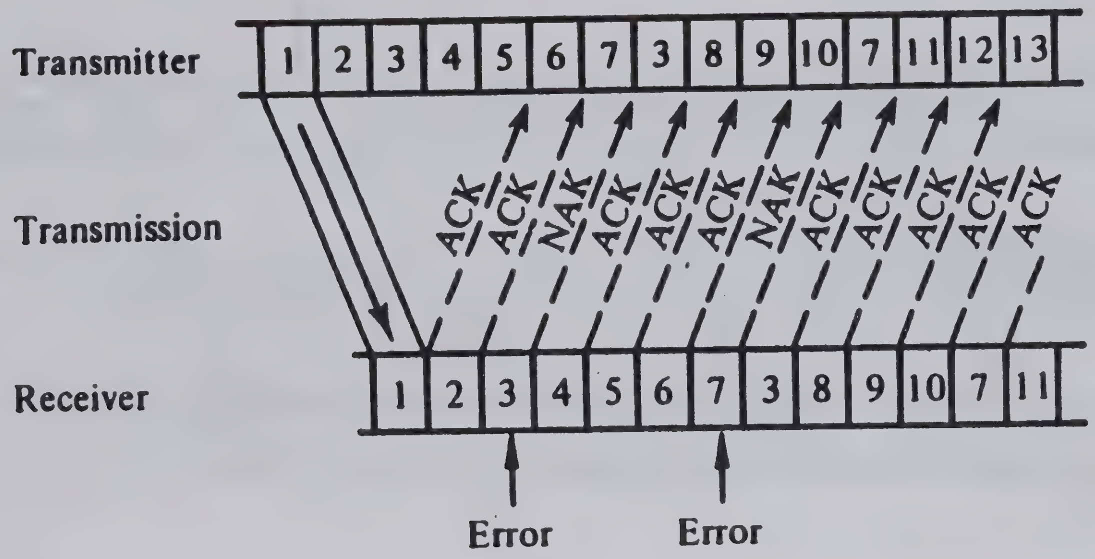


Figure 15.3 Selective-repeat

ARQ Efficiency

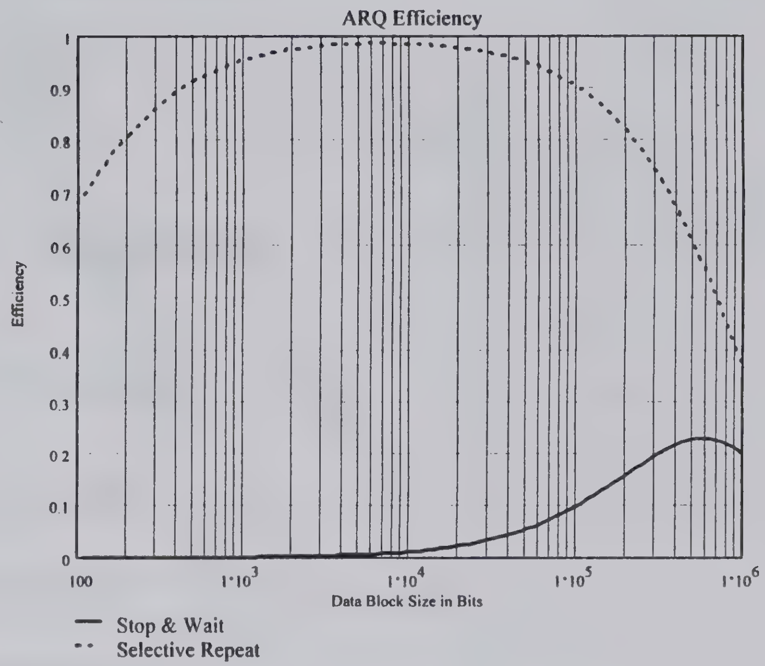
Header = 48 bits

Service time = 1 ms

Propagation time = 270 ms

Data rate = $1.544*10^6$

Pb = 10^{-6}



FEC Coding

PROBABILITY BIT ERROR

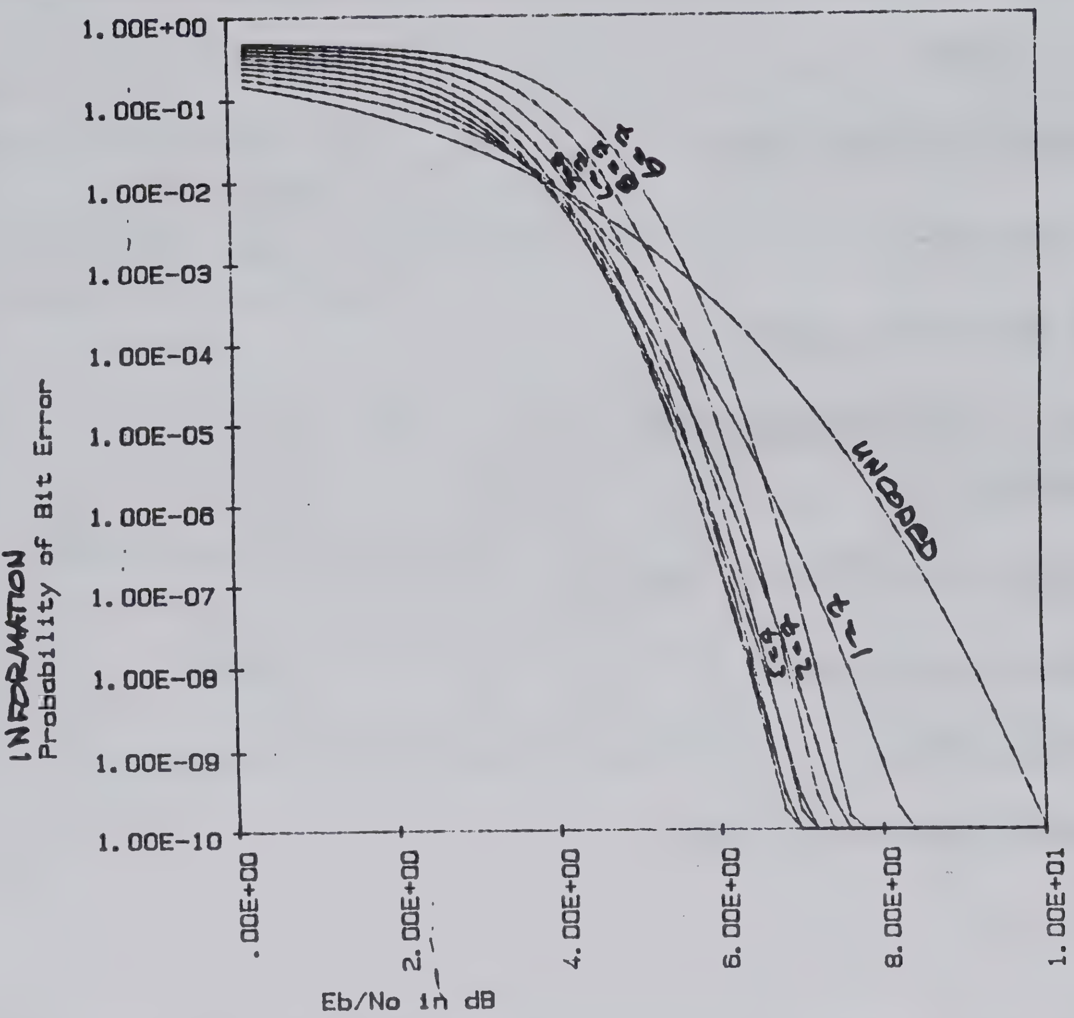
Decreases Pb for given Eb/No

or

Decreases Eb/No for given Pb

- **Types of FEC codes**
  - **Block Codes**
  - **Convolutional Codes**
  - **Concatenated Codes**
  - **Trellis Codes**
  - **Turbo Codes**

Coded Bit Error Probability



Block Codes

Length - n bits

Information - k bits, k<n

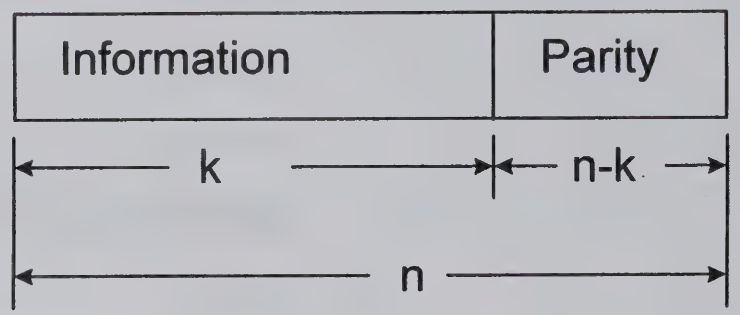
Parity - n-k bits

Denoted as (n,k) code

Code rate - k/n (bandwidth efficiency)

Commonly used block codes

- Hamming code
- BCH code
- Reed-Solomon Code



Block Code Performance

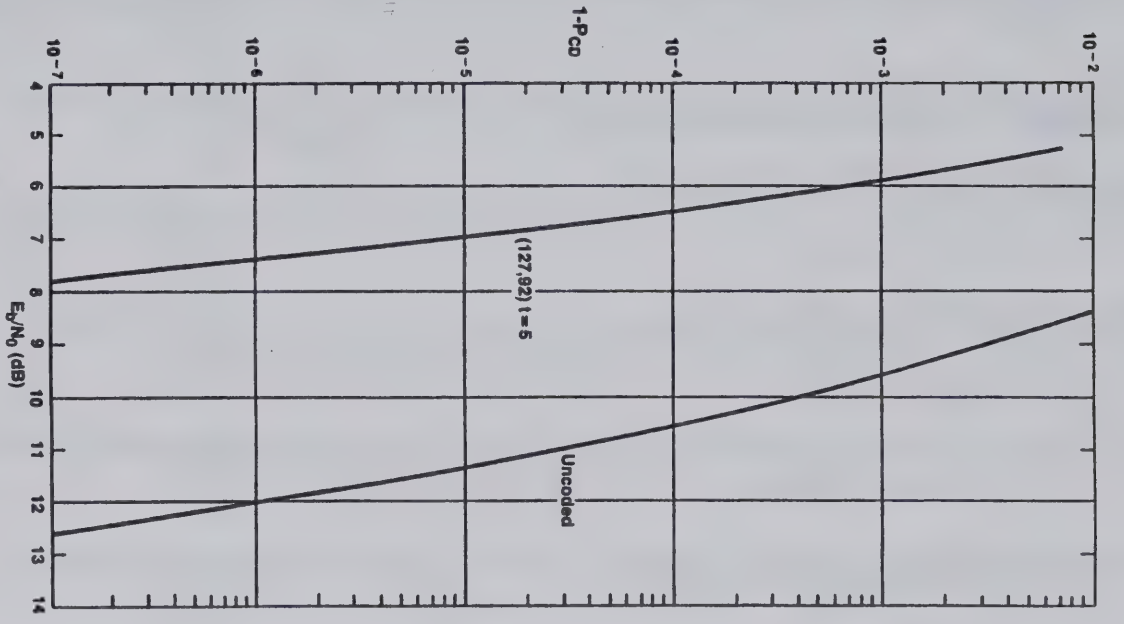


FIGURE 11.8. 1 − P_{CD} vs. E_b/N_0 for the (127,92) $t = 5$ binary BCH code and an uncoded 92-bit transmission.

Convolutional Codes

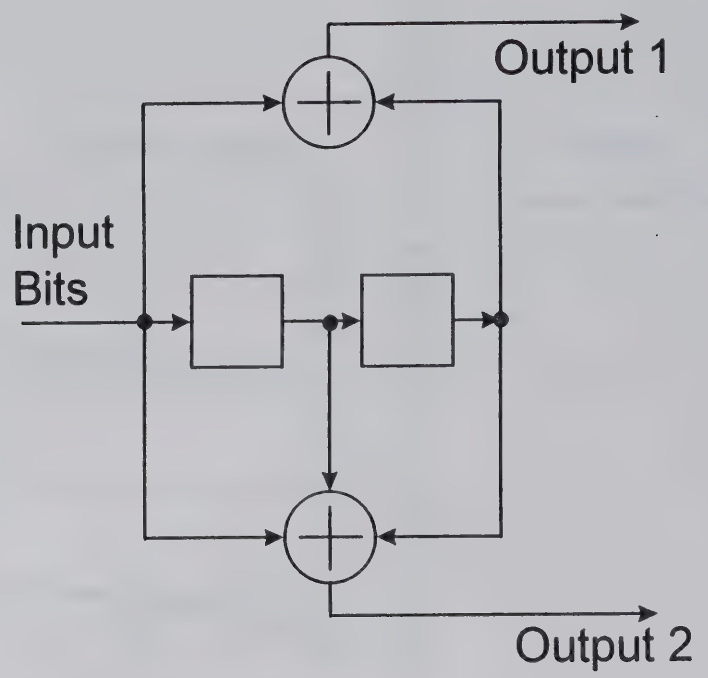
Encoding is essentially a convolution operation

"Optimal" Codes are found by exhaustive search

Defined as (k,n,K)

- **k - input bits**
- **n - output bits**
- **K - Constraint length**

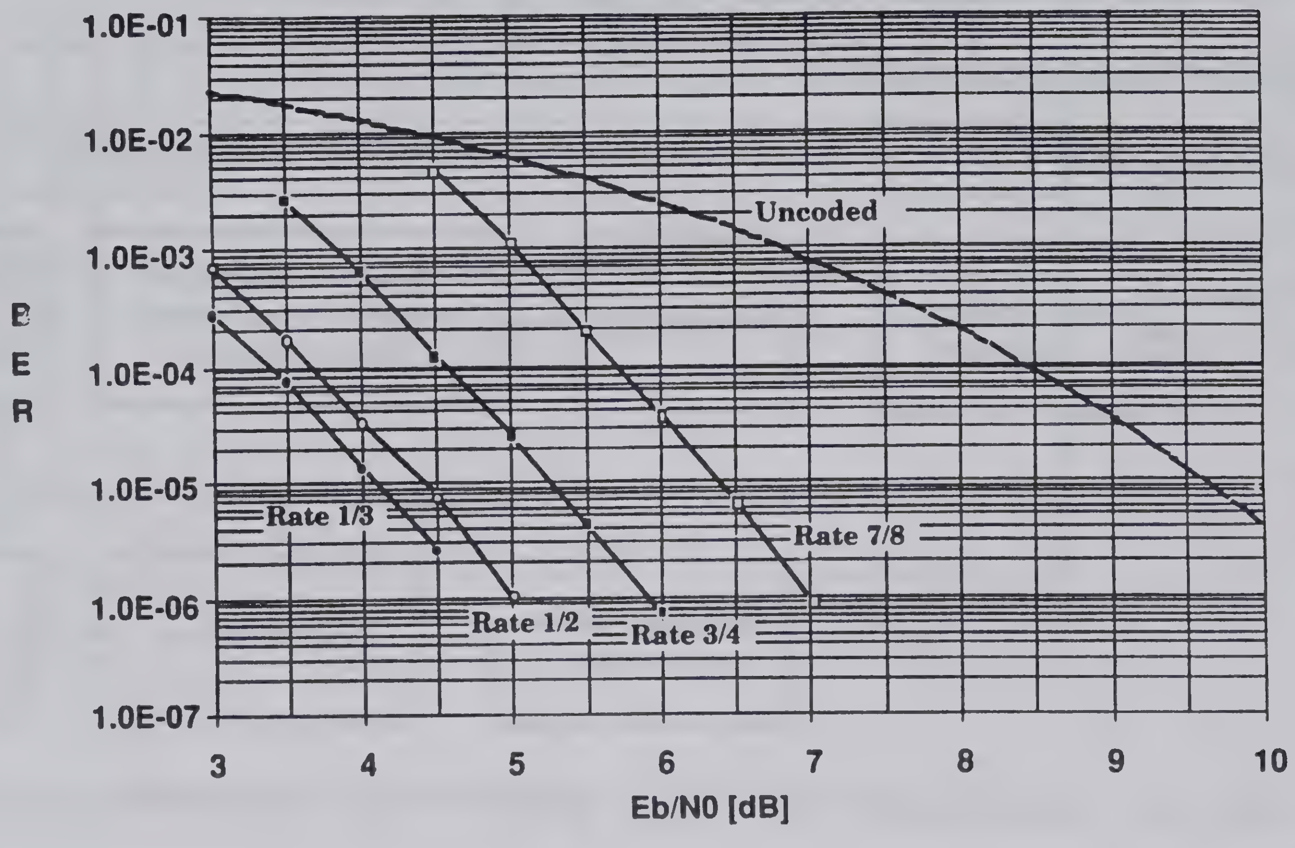
Code rate - k/n



Convolutional Code Performance

3- 70

DECODER PERFORMANCE (With Ideal Soft-Decision PSK Modem)



Concatenated Code

Use two correction codes on top of each other

Inner code does well in low SNR environment

Outer code corrects burst errors output from inner code

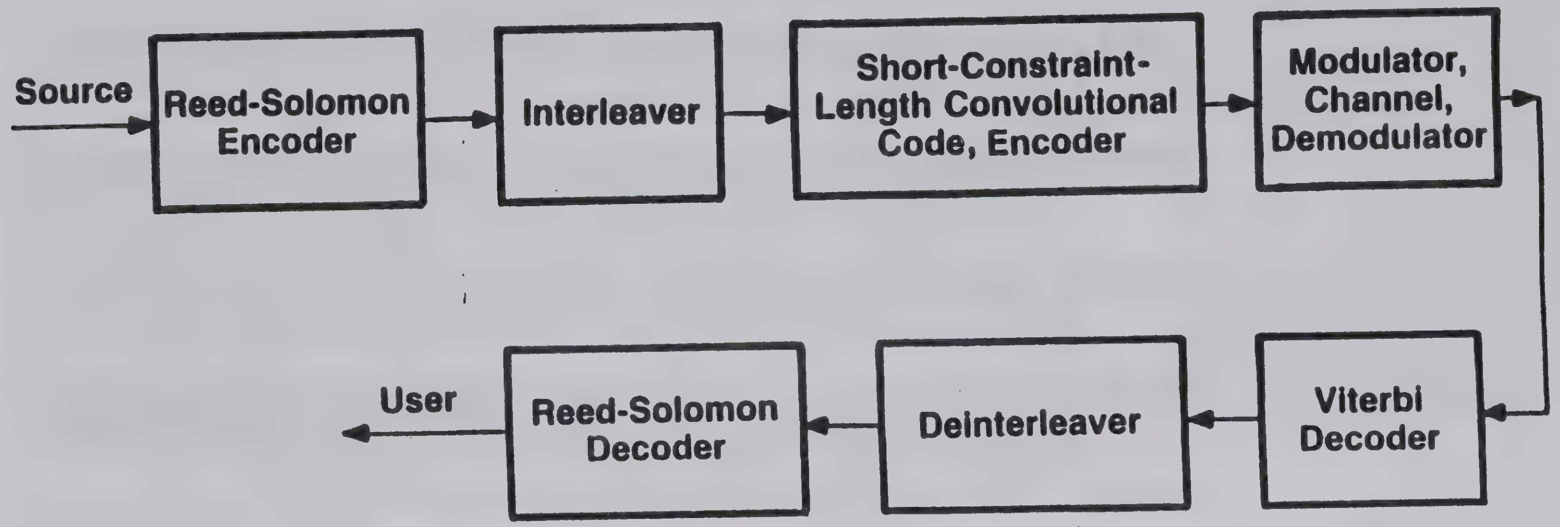
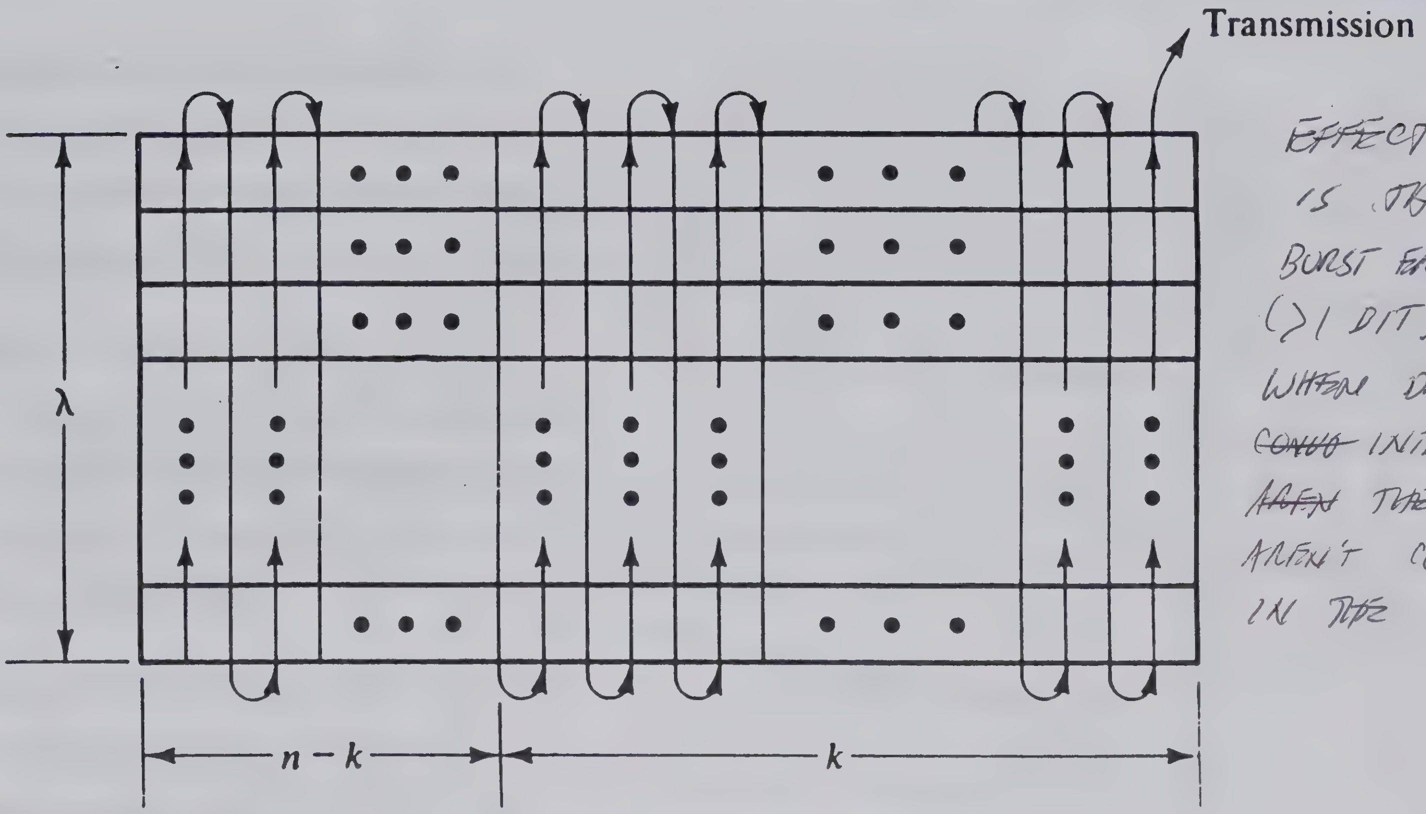


FIGURE 11.4. Concatenated code using a short-constraint-length convolutional code and an RS code.

Interleaver



EFFECT IS THAT BURST ERRORS (>1 BIT), WHEN DE-~~CONVO~~ INTERLEAVER, ~~AREN~~ THE ERRORS AREN'T CONSECUTIVE IN THE DATA STREAM.

Figure 9.5 Transmission of an interleaved code.

Concatenated Code Performance

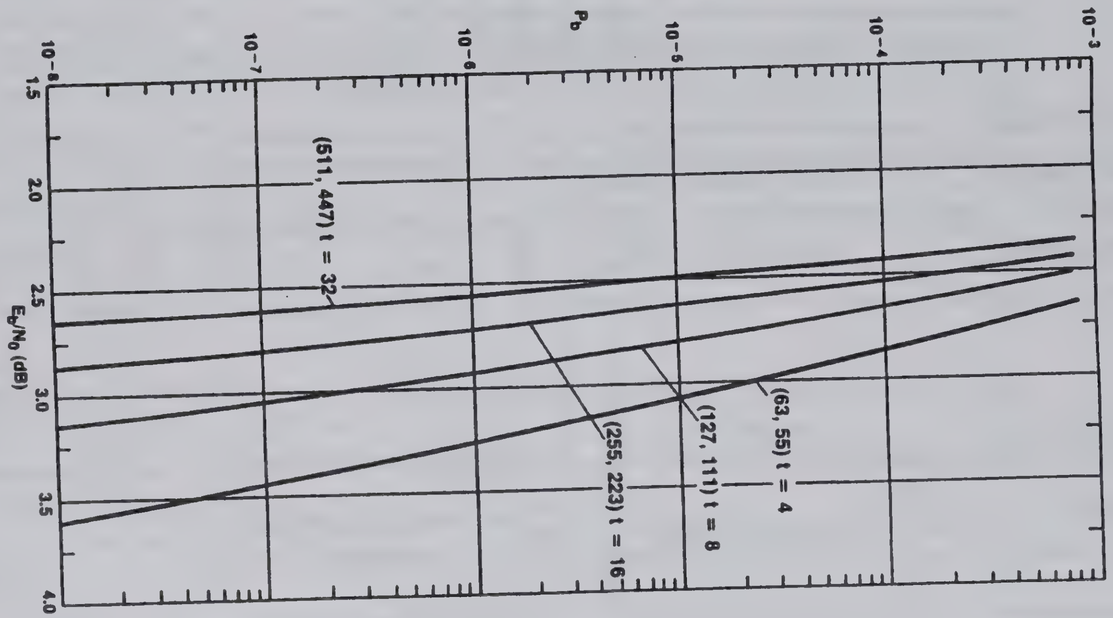
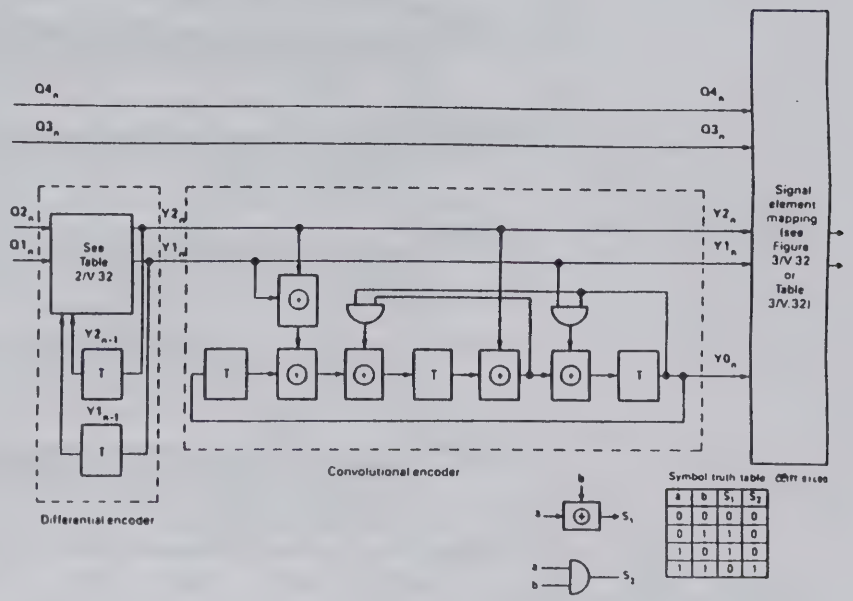


FIGURE 11.5. Post-decoding bit-error rate for several concatenated codes using the $k = 7$, rate-1/2 convolutional code as the inner code. Outer codes are RS codes defined on *GF*(64), *GF*(128), *GF*(256), and *GF*(512).

Trellis Codes

3- 74

- **Block and Convolutional codes add redundant symbols and increase bandwidth**
- **Trellis codes add redundancy in terms of alphabet size (does not require increase in bandwidth)**
- **Instead of using QPSK modulation (4 state), encode with 8-PSK (8-state)**



Symbol truth table

a	b	S1	S2
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

FIGURE 2/V.32

Trellis coding at 9600 bit/s

Trellis Code Performance

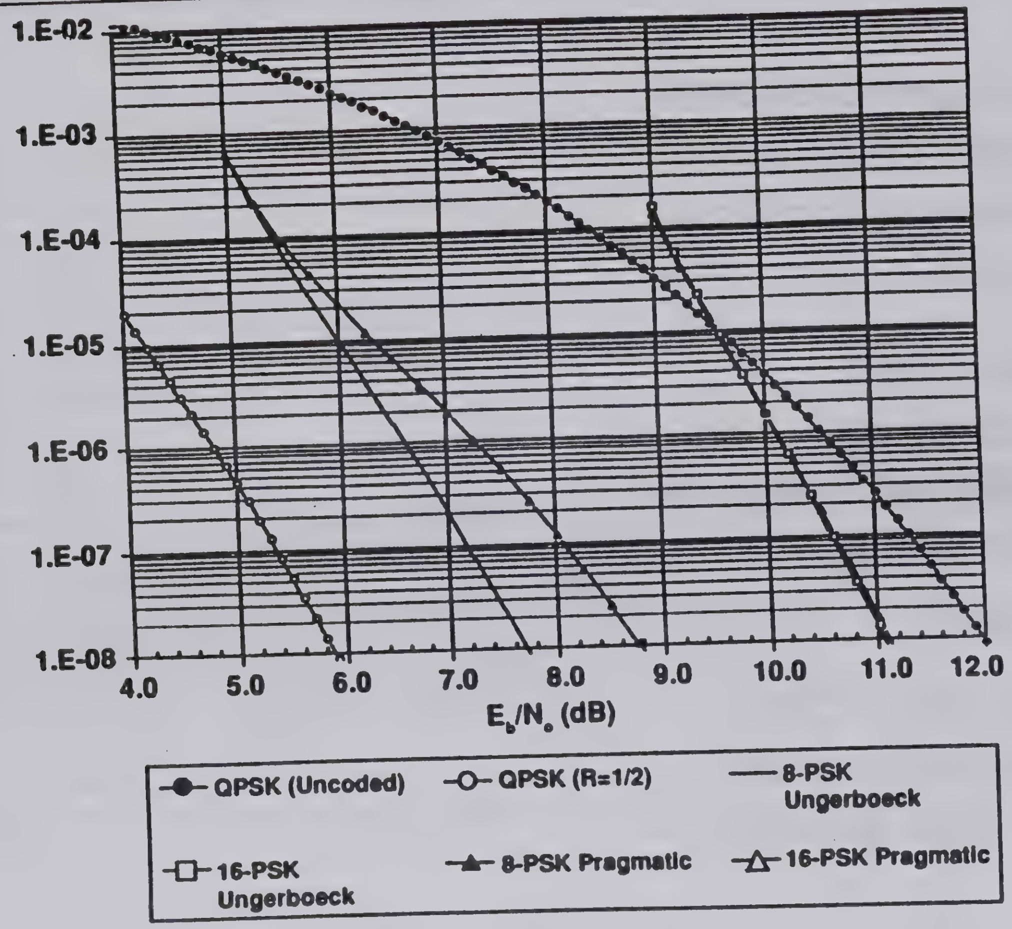


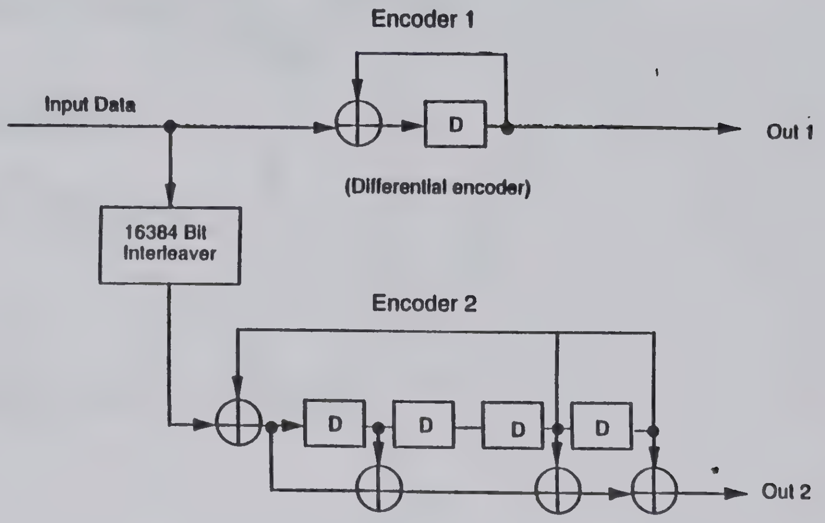
Fig. 9. BER vs. E_b/N_o for the pragmatic coder/modulator (PSK modulation).

Turbo Codes

- Parallel concatenated convolutional codes with long interleaver
- Best code performance
- Within 2 dB of capacity theorem

Rate 1/2 Turbo Code

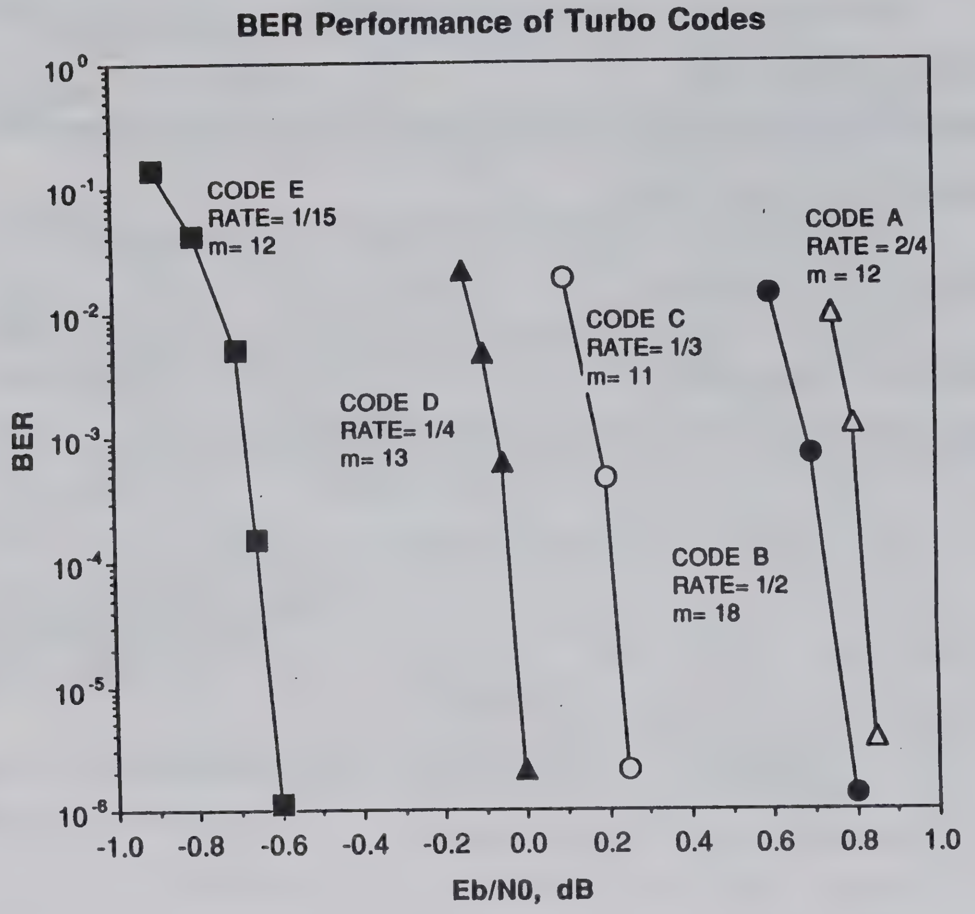
(Found by Divsalar and Pollara, 1995)



Bit Error Rate = 10^{-6} at Bit SNR=0.85 dB

Can be used with QPSK to achieve 1 bit/sec./Hz

Turbo Code Performance



Coding Summary

What code to use??

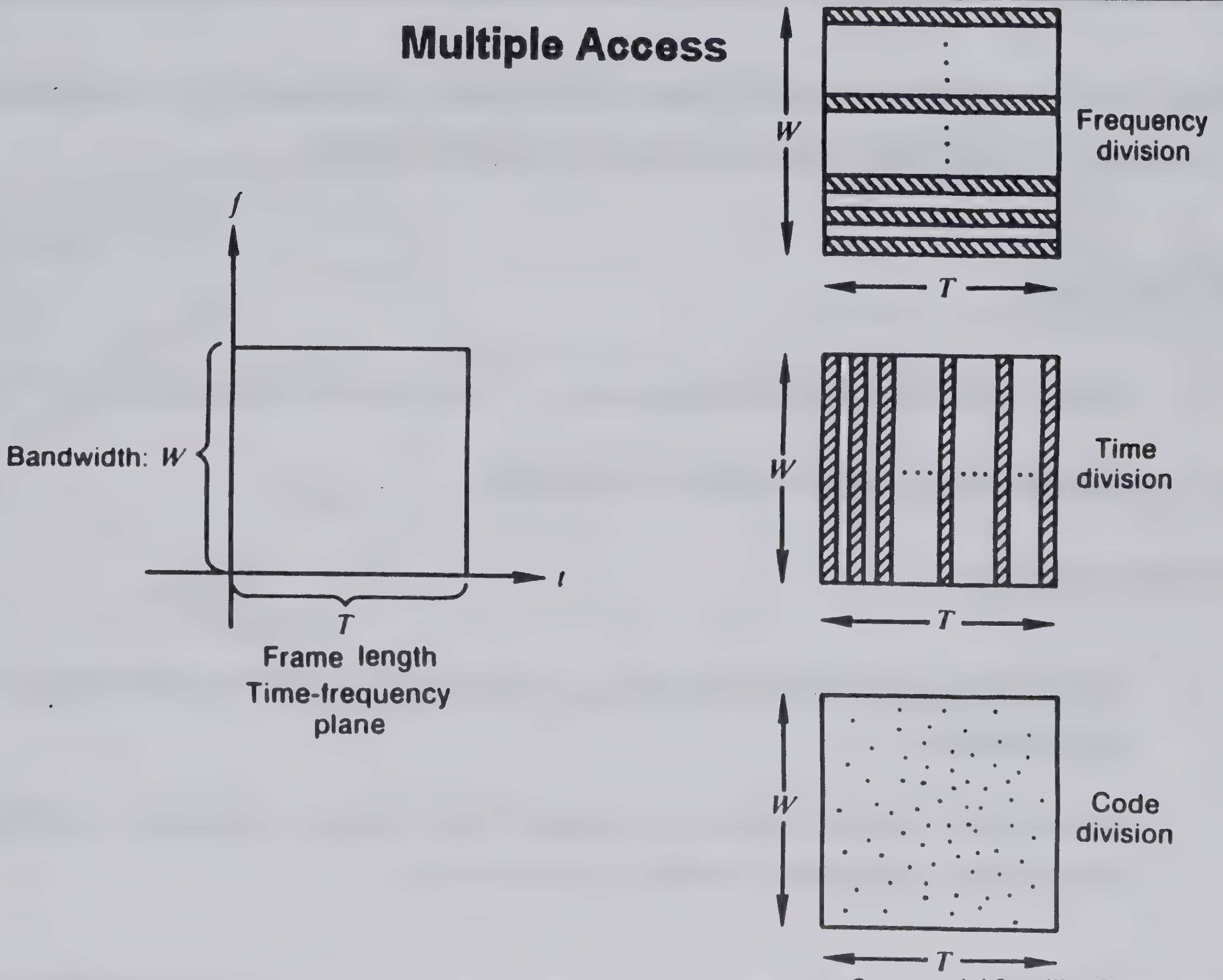
Depends on requirements

- **Power efficiency**
- **Bandwidth efficiency**
- **Latency**
- **Transmission environment**

Multiple-Access

Multiple Access

Multiple Access



FDMA

Each earth station assigned different frequency band within overall satellite transponder bandwidth

Advantage:

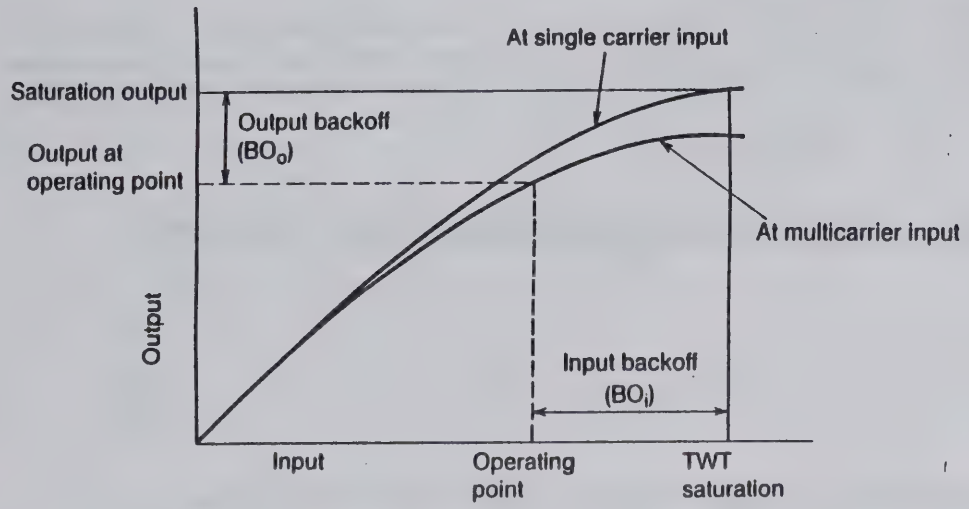
- **Easy to select only channel of interest by bandpass filtering**
- **Minimum data rate per channel**

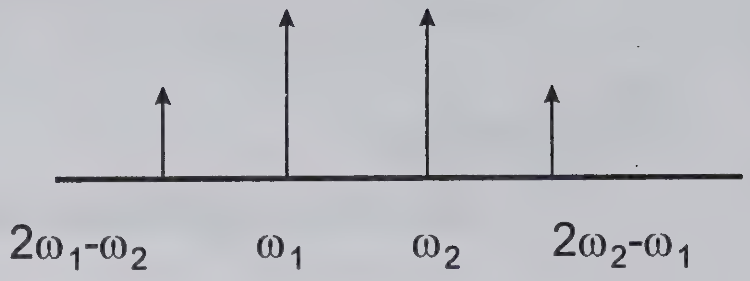
Disadvantage:

HIGH POWER AMPLIFIER

- **Intermodulation products produced by HPA operating near saturation**
- **Requires output power backoff (reduced amplifier efficiency to minimize intermodulation products**

Intermodulation





Intermodulation Spectrum

TDMA

Each earth station transmits in different time slot in larger time frame

Advantage:

- **No intermodulation noise, only one carrier operating at a time**

Disadvantage:

- **All transmitters must operate at high bandwidth all the time**
- **Each transmitter is independent, receiver must recover carrier and bit sync for each burst**

TDMA Burst

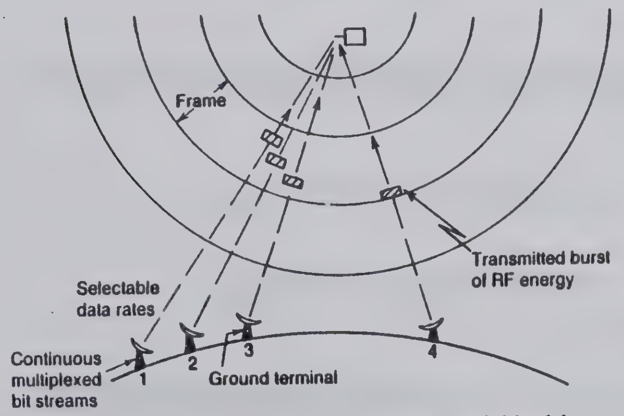

Frame
Transmitted burst of RF energy
Selectable data rates
Continuous multiplexed bit streams
1
2
3
4
Ground terminal

Figure 6.6 Stations in a TDMA network must transmit individual bursts of RF energy in such a way that the bursts arrive at the satellite in a prescribed order. (*Source:* J. J. Spilker, Jr., *Digital Communications by Satellite*, copyright © 1977, p. 266. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.)

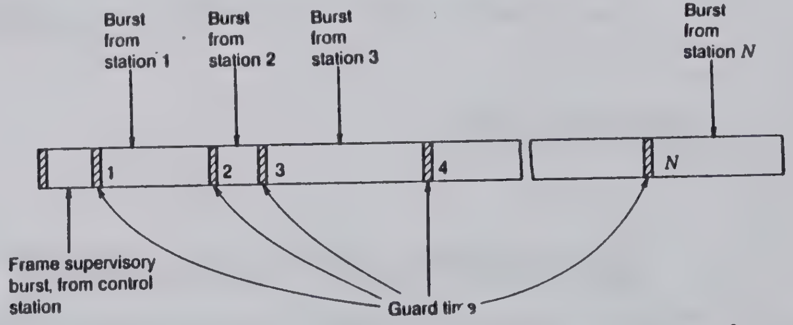


Figure 6.7 The structure of a TDMA frame. Each station transmits once per frame. Each frame contains a supervisory or reference burst. (*Source:* James Martin, *Communications Satellite Systems*, copyright © 1978, p. 248. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.)

TDMA Synchronization

Accurate time synchronization required to avoid user overlaps

Need to know

- **Timing Reference**
- **Range to satellite**

Two techniques for synchronization

- **Satellite loop-back synchronization**
- **Cooperative synchronization**

CDMA

All users use all the bandwidth all the time

Each user uses a unique spread spectrum code to differentiate his signal from that of the other users

Advantage:

- **Users do not have to coordinate frequency assignments or time slots**

Disadvantage:

- **Practical considerations limit usage to small number of simultaneous users**

MUST HAVE DYNAMIC RANGE "RESERVE" TO BRING ALL REMOTES TO APPROX. SAME LEVEL.

Direct Sequence Spreading

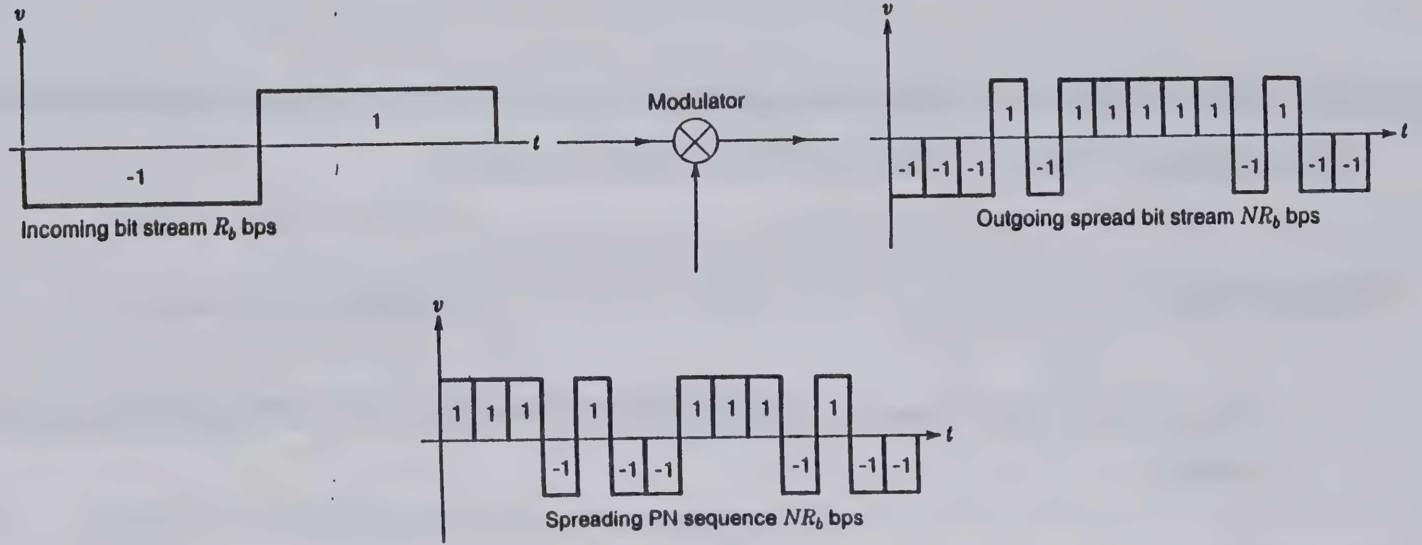

v
-1
1
t
Incoming bit stream R_b bps
Modulator
v
-1
-1
-1
1
-1
1
1
1
1
1
-1
1
-1
-1
t
Outgoing spread bit stream NR_b bps
v
1
1
1
-1
1
-1
-1
1
1
1
-1
1
-1
-1
t
Spreading PN sequence NR_b bps

Figure 6.16 The basic principle of a PN sequence spread-spectrum system. Each incoming bit is multiplied by the same PN sequence. In this example the incoming bit stream is $-1\ 1$ and the PN sequence is $1\ 1\ 1\ -1\ 1\ -1\ -1$.

Interference Limited

CDMA is an interference limited channel

- **Each user looks like added noise to every other user**

$$\frac{C}{I} = \frac{C}{(n-1)*C}$$

n is number of simultaneous users

$$\frac{E_b}{I_o} = \frac{C/R_b}{I/W} = \frac{W/R_b}{(n-1)}$$

$$n = 1 + \frac{W/R_b}{E_b/N_o}$$

$$\frac{C}{I_t} = \frac{1}{\frac{1}{C/N_u} + \frac{1}{C/I} + \frac{1}{C/N_d}}$$

Lowest Value term dominates

Want to minimize satellite power

C/N_d min

Aloha Channel

Type of TDMA

User transmits whenever he has data to send

Some users packets destroyed by collision with other users

Transmitter determines whether collision has occurred by monitoring the downlink channel or not receiving ACKnowledge

In case of collision, transmitter waits random time and sends again

Aloha sometimes called CSMA/CD

Aloha Timing

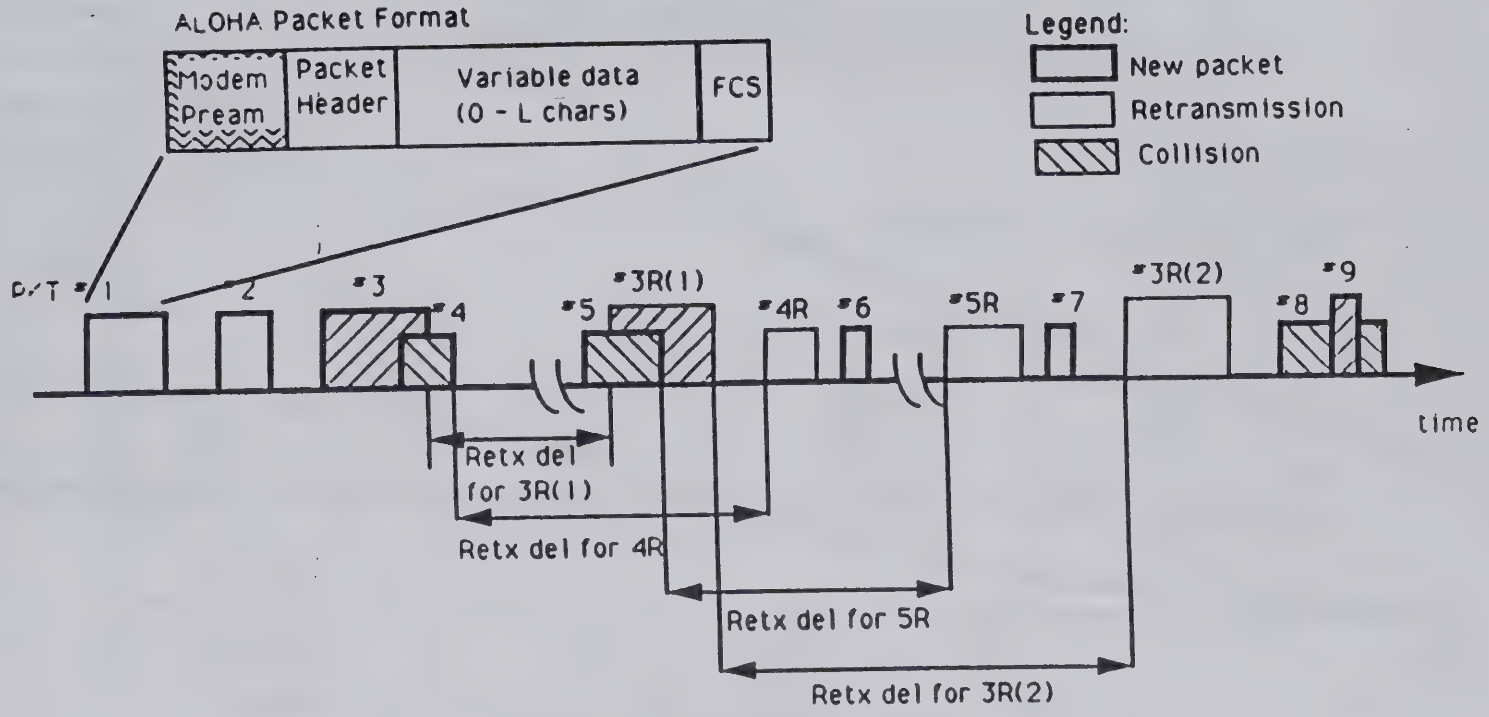


Fig. 7.3 *Illustration of channel events for the ALOHA protocol*

Slotted Aloha Timing

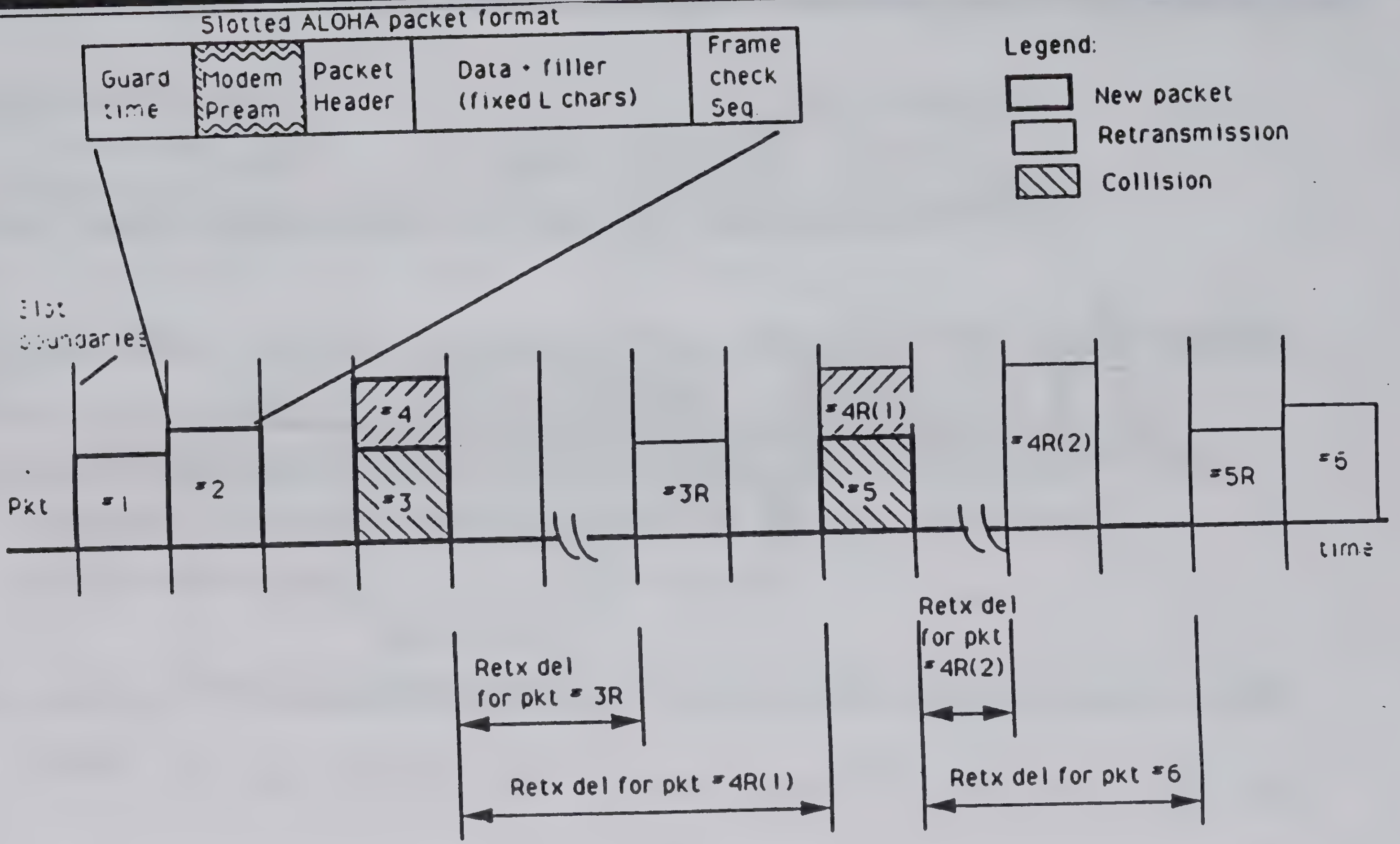
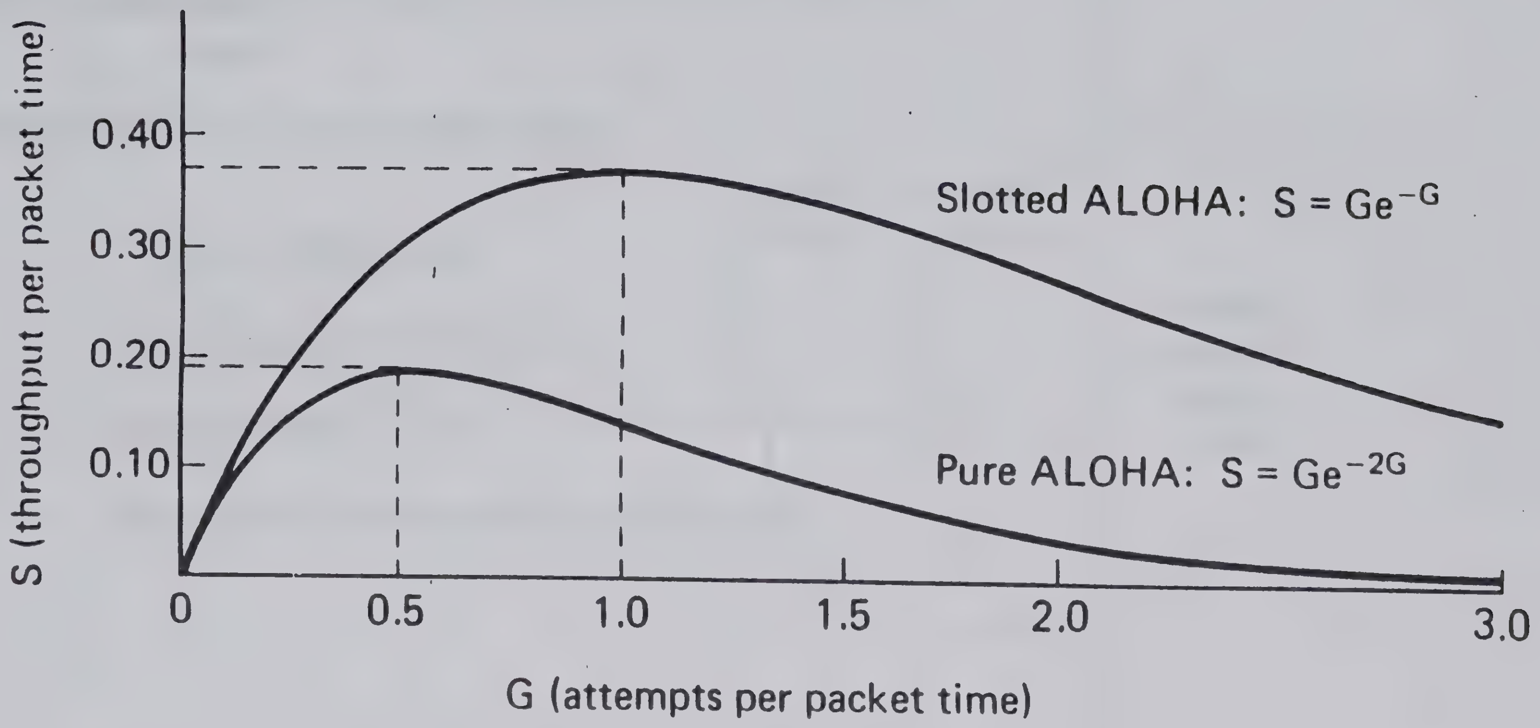
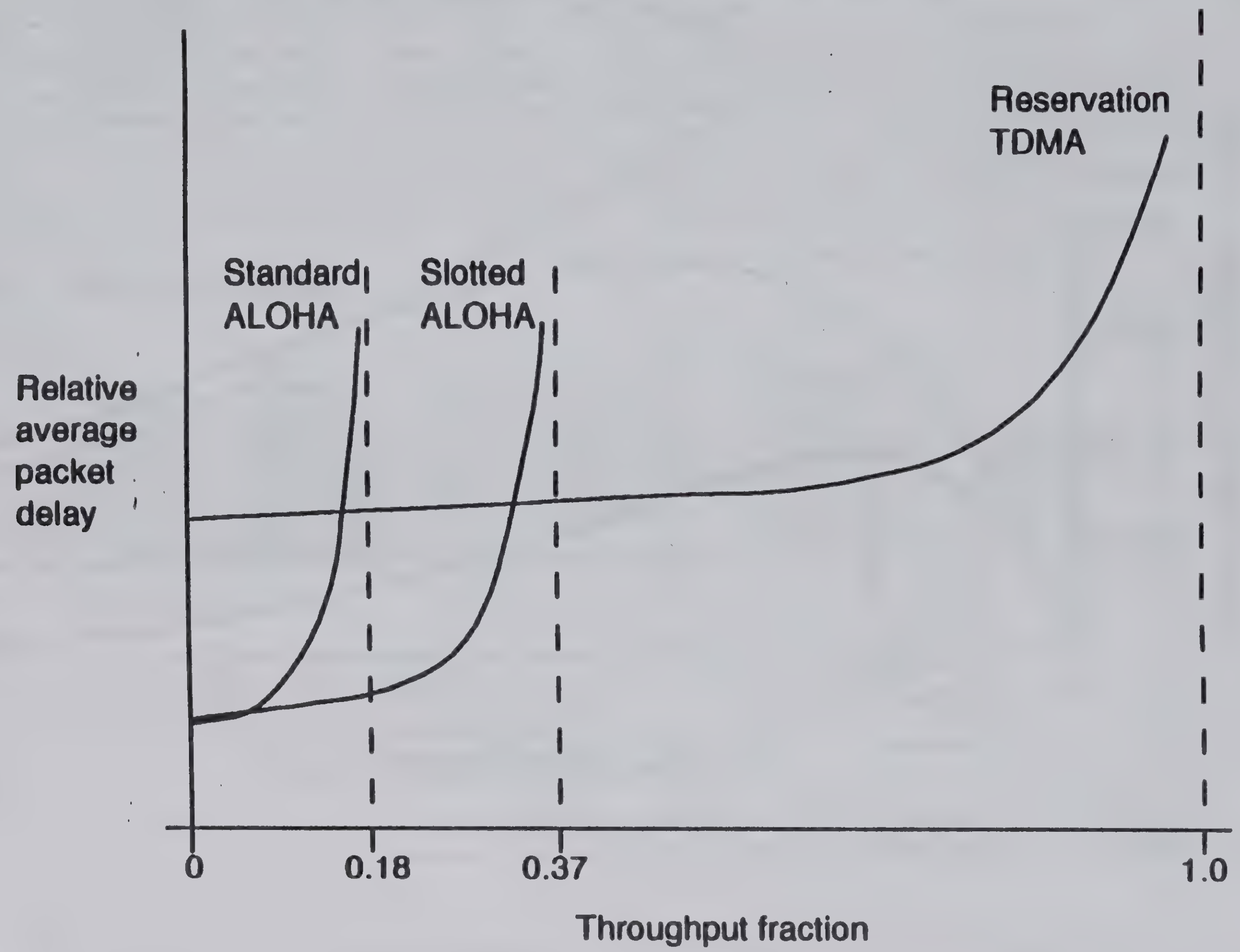


Fig. 7.5 *Illustration of channel events for the slotted ALOHA protocol*

Aloha Throughput Performance



Aloha Delay Performance



Multiple-Access Summary

What Multiple-access scheme to use??

Depends on requirements

- **Power efficiency**
- **Throughput efficiency**
- **Equipment cost**
- **Nature of information channels**

Communication Summary

Looked at

- Link budgets
- Modulation
- Coding
- Multiple-access

Major requirements drivers

- Power efficiency
- Bandwidth efficiency
- Data latency
- Nature of source data

Purpose

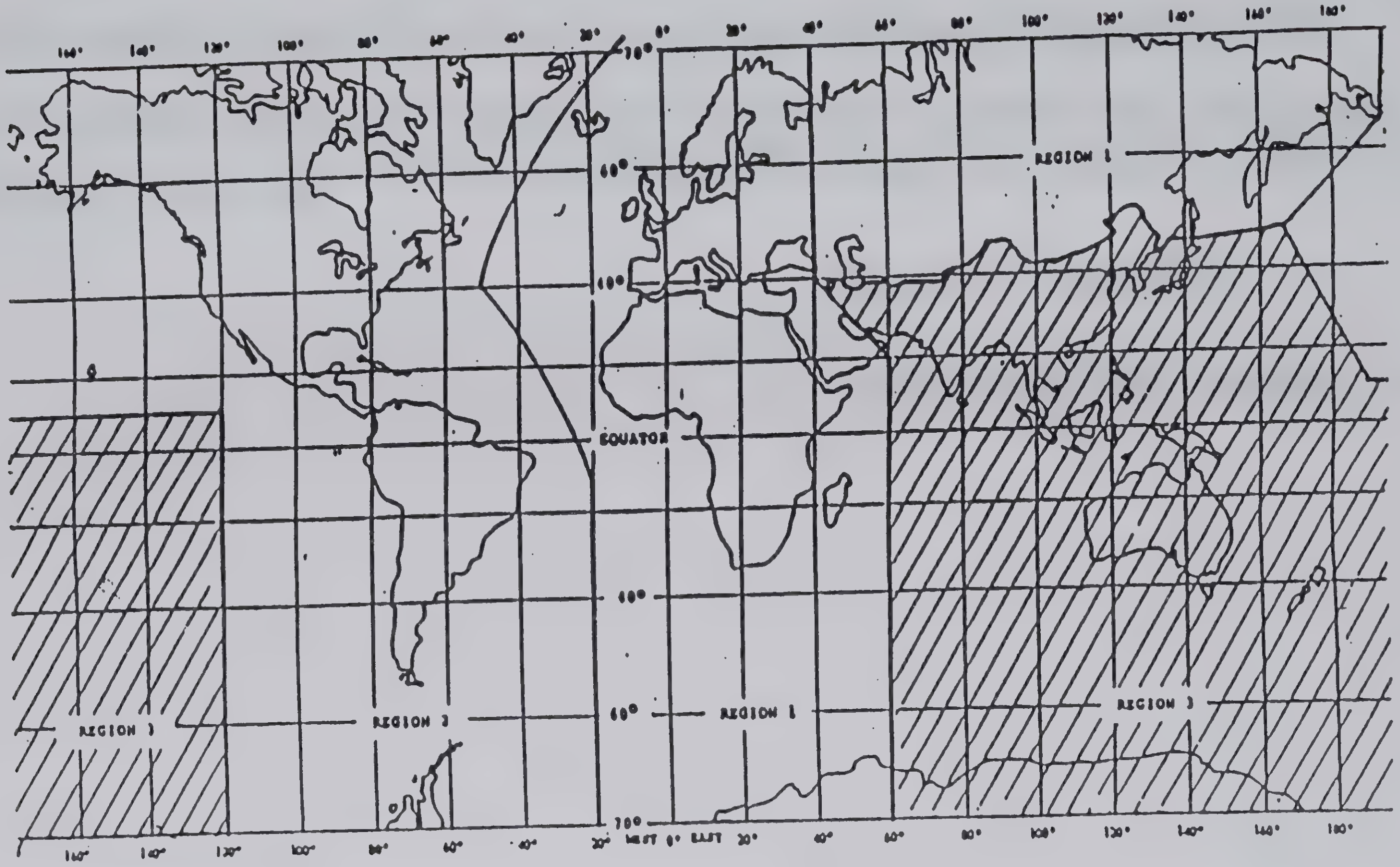
- **Provide coordination and recommendations to promote coexistence of various services without interference**

Regulations

- **ITU - Radio Regulations**
- **FCC - Code of Federal Regulations, Title 47,**
    - **Satellites - Part 25**
- **NTIA - NTIA manual**

ITU Regions

4- 6



Frequency Allocations

Service	Downlink	Uplink
TT&C	137 - 138 MHz	1427 - 1429 MHz
	401 - 402	
	2.2 - 2.3 GHz	1.75 - 1.85 GHz
Fixed		
C-band	3.7 - 4.2 GHz	5.925 - 7.075 GHz
Ku-band	11.7 - 12.2 GHz	14.0 - 14.5 GHz
Ka-band	17.3 - 20.2 GHz	27.5 - 30.0 GHz
BSS		
S-band	2310 -2360 MHz	
Ku-band	12.2 - 12.7 GHz	17.3 - 17.8 GHz
Mobile		
Maritime	1530 - 1544	1626.5 - 1645.5
Aeronautical	1545 - 1559	1646.5 - 1660
Land	2483.5 - 2500	1610 - 1626.5

Frequency Allocation

Other	
Space Research	**2.025 - 2.110 GHz**
	2.2 - 2.29 GHz
Intersatellite	**22.55 - 23.55 GHz**
	54.2 - 58.2 GHz
	59.0 - 64.0 GHz
DSN	**8.4 - 8.5 GHz**
EES	**8.025 - 8.4 GHz**

FIG[illegible]EASUREMENT SITE
FIGU[illegible]—TYPICAL AUDIO WAVEFORM
FIGURE 3—EXAMPLE OF IDEAL EPIRB SPECTRUM
FIGURE 4—EXAMPLE OF EPIRB CARRIER COMPONENT

AUTHORITY: Sec. 4, 302, 303, and 307 of the Communications Act of 1934, as amended, 47 U.S.C. Sections 154, 302, 303 and 307, unless otherwise noted.

SOURCE: 28 FR 12465, Nov. 22, 1963, unless otherwise noted.

Subpart A—Terminology

§2.1 Terms and definitions.

(a) Where a term or definition appears in this part of the Commission's Rules, it shall be the definitive term or definition and shall prevail throughout the Commission's Rules.

(b) The source of each definition is indicated as follows:

CONV—*International Telecommunication Convention*, Malaga-Torremolinos, 1973.
RR—*Radio Regulations*, Geneva, 1982.
FCC—Federal Communications Commission.

(c) The following terms and definitions are issued:

Accepted Interference.[1] Interference at a higher level than defined as permissible interference and which has been agreed upon between two or more administrations without prejudice to other administrations. (RR)

Active Satellite. A satellite carrying a station intended to transmit or retransmit radiocommunication signals. (RR)

Active Sensor. A measuring instrument in the earth exploration-satellite service or in the space research service by means of which information is obtained by transmission and reception of radio waves. (RR)

Administration. Any governmental department or service responsible for discharging the obligations undertaken in the Convention of the International Telecommunication Union and the Regulations. (CONV)

Aeronautical Earth Station. An earth station in the fixed-satellite s[illegible] or, in some cases, in the aeronau[illegible] mobile-satellite service, located at a specified fixed point on land to provide a feeder link for the aeronautical mobile-satellite service. (RR)

Aeronautical Fixed Service. A radiocommunication service between specified fixed points provided primarily for the safety of air navigation and for the regular, efficient and economical operation of air transport. (RR)

Aeronautical Fixed Station. A station in the aeronautical fixed service. (RR)

Aeronautical Mobile Off-Route (OR) Service. An aeronautical mobile service intended for communications, including those relating to flight coordination, primarily outside national or international civil air routes. (RR)

Aeronautical Mobile Route (R) Service. An aeronautical mobile service reserved for communications relating to safety and regularity of flight, primarily along national or international civil air routes. (RR)

Aeronautical Mobile-Satellite Off-Route (OR) Service. An aeronautical mobile-satellite service intended for communications, including those relating to flight coordination, primarily outside national and international civil air routes. (RR)

Aeronautical Mobile-Satellite Route (R) Service. An aeronautical mobile-satellite service reserved for communications relating to safety and regularity of flights, primarily along national or international civil air routes. (RR)

Aeronautical Mobile-Satellite Service. A mobile-satellite service in which mobile earth stations are located on board aircraft; survival craft stations and emergency position-indicating radiobeacon stations may also participate in this service. (RR)

Aeronautical Mobile Service. A mobile service between aeronautical stations and aircraft stations, or between aircraft stations, in which survival craft stations may participate; emergency position-indicating radiobeacon stations may also participate in this service on designated distress and emergency frequencies. (RR)

Aeronautical Radionavigation-Satellite Service. A radionavigation-satellite service in which earth stations are located on board aircraft. (RR)

Aeronautical Radionavigation Service. A radio-navigation service intended for the benefit and for the safe operation of aircraft. (RR)

Aeronautical Station. A land station in the aeronautical mobile service.

NOTE: In certain instances, an aeronautical station may be located, for example, on board ship or on a platform at sea. (RR)

Aircraft Earth Station. A mobile earth station in the aeronautical mobile-satellite service located on board an aircraft. (RR)

Aircraft Station. A mobile station in the aeronautical mobile service, other than a survival craft station, located on board an aircraft. (RR)

Allocation (of a frequency band). Entry in the Table of Frequency Allocations of a given frequency band for the purpose of its use by one or more terrestrial or space radiocommunication services or the radio astronomy service under specified conditions. This term shall also be applied to the frequency band concerned. (RR)

Allotment (of a radio frequency or radio frequency channel). Entry of a designated frequency channel in an agreed plan, adopted by a competent conference, for use by one or more administrations for a terrestrial or space radiocommunication service in one or more identified countries or geographical area and under specified conditions. (RR)

Altitude of the Apogee or Perigee. The altitude of the apogee or perigee above a specified reference surface serving to represent the surface of the Earth. (RR)

Amateur-Satellite Service. A radiocommunication service using space stations on earth satellites for the same purposes as those of the amateur service. (RR)

Amateur Service. A radiocommunication service for the purpose of self-training, intercommunication and technical investigations carried out by amateurs, that is, by duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest. (RR)

Amateur Station. A station in the amateur service. (RR)

Assigned Frequency [illegible] frequency band [illegible]d to a statio (RR)

Assigned Frequency Band. The fr quency band within which the emissio of a station is authorized; the width the band equals the necessary ban width plus twice the absolute value the frequency tolerance. Where spa stations are concerned, the assigne frequency band includes twice the ma imum Doppler shift that may occur relation to any point of the Earth surface. (RR)

Assignment (of a radio frequency radio frequency channel). Authorizati given by an administration for a rad station to use a radio frequency radio frequency channel under spe fied conditions. (RR)

Base Earth Station. An earth stati in the fixed-satellite service or, some cases, in the land mobile-satelli service, located at a specified fix point or within a specified area on la to provide a feeder link for the la mobile-satellite service. (RR)

Base Station: A land station in t land mobile service. (RR)

Broadcasting-Satellite Service. radiocommunication service in whi signals transmitted or retransmitt by space stations are intended for rect reception by the general public.

NOTE: In the broadcasting-satellite ser the term *direct reception* shall encom both individual reception and community ception. (RR)

Broadcasting Service. radiocommunication service in whi the transmissions are intended fo rect reception by the general publ This service may include sound tra missions, television transmissions other types of transmission. (CONV)

Broadcasting Station. A station in t broadcasting service. (RR)

Carrier Power (of a radio transmitt The average power supplied to the tenna transmission line by a transm ter during one radio frequency cy taken under the condition of no mo lation. (RR)

Characteristic Frequency. A frequen which can be easily identified a measured in a given emission.

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[1] The terms *permissible interference* and *accepted interference* are used in the coordination of frequency assignments between administrations.

NOT[illegible] [illegible]er frequency may, for example, b[illegible] [illegible]ed as the characteristic frequency[illegible]

Class of Emission. The set of characteristics of an emission, designated by standard symbols, e.g., type of modulation, modulating signal, type of information to be transmitted, and also if appropriate, any additional signal characteristics. (RR)

Coast Earth Station. An earth station in the fixed-satellite service or, in some cases, in the maritime mobile-satellite service, located at a specified fixed point on land to provide a feeder link for the maritime mobile-satellite service. (RR)

Coast Station. A land station in the maritime mobile service. (RR)

Community Reception (in the broadcasting-satellite service). The reception of emissions from a space station in the broadcasting-satellite service by receiving equipment, which in some cases may be complex and have antennae larger than those for individual reception, and intended for use: (1) by a group of the general public at one location; or (2) through a distribution system covering a limited area. (RR)

Coordinated Universal Time (UTC). Time scale, based on the second (SI), as defined and recommended by the CCIR,[2] and maintained by the Bureau International de l'Heure (BIH).

NOTE: For most practical purposes associated with the Radio Regulations, UTC is equivalent to mean solar time at the prime meridian (0 degrees longitude), formerly expressed in GMT. (RR)

Coordination Area. The area associated with an earth station outside of which a terrestrial station sharing the same frequency band neither causes nor is subject to interfering emissions greater than a permissible level. (RR)

Coordination Contour. The line enclosing the coordination area. (RR)

Coordination Distance. Distance on a given azimuth from an earth station beyond which a terrestrial causes nor is subject to interfering emissions greater than a permissible level. (RR)

Deep Space. Space at distance from the Earth equal to, or greater than, 2×10^6 kilometers. (RR)

Direct Sequence Systems. A direct sequence system is a spread spectrum system in which the incoming information is usually digitized, if it is not already in a binary format, and modulo 2 added to a higher speed code sequence. The combined information and code are then used to modulate a RF carrier. Since the high speed code sequence dominates the modulating function, it is the direct cause of the wide spreading of the transmitted signal.

Duplex Operation. Operating method in which transmission is possible simultaneously in both directions of a telecommunication channel.[3] (RR)

Earth Exploration-Satellite Service. A radiocommunication service between earth stations and one or more space stations, which may include links between space stations in which:

(1) Information relating to the characteristics of the Earth and its natural phenomena is obtained from active sensors or passive sensors on earth satellites;

(2) Similar information is collected from air-borne or earth-based platforms;

(3) Such information may be distributed to earth stations within the system concerned;

(4) Platform interrogation may be included.

NOTE: This service may also include feeder links necesary for its operation. (RR)

Earth Station. A station located either on the earth's surface or within the major portion of earth's atmosphere and intended for communication:

(1) With one or more space stations; or

(2) With one or more stations of the same kind by means of one or more reflecting satellites or other objects in space. (RR)

Effective Radiated Power (e.r.p) (in a given direction). The product of the power supplied to the antenna and its gain relative to a half-wave dipole in a given direction. (RR)

Emergency Position-Indicating Radiobeacon Station. A station in the mobile

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[2] The full definition is contained in CCIR Recommendation 460-2.

[3] In general, duplex operation and semi-duplex operation require two frequencies in radiocommunication; simplex operation may use either one or two.

service the emissions of which are intended to facilitate search and rescue operations. (RR)

Emission. Radiation produced, or the production of radiation, by a radio transmitting station.

NOTE: For example, the energy radiated by the local oscillator of a radio receiver would not be an emission but a radiation. (RR)

Equivalent Isotropically Radiated Power (e.i.r.p.). The product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna. (RR)

Equivalent Monopole Radiated Power (e.m.r.p.) (in a given direction). The product of the power supplied to the antenna and its gain relative to a short vertical antenna in a given direction. (RR)

Equivalent Satellite Link Noise Temperature. The noise temperature referred to the output of the receiving antenna of the earth station corresponding to the radio-frequency noise power which produces the total observed noise at the output of the satellite link excluding the noise due to interference coming from satellite links using other satellites and from terrestrial systems. (RR)

Experimental Station. A station utilizing radio waves in experiments with a view to the development of science or technique.

NOTE: This definition does not include amateur stations. (RR)

Facsimile. A form of telegraphy for the transmission of fixed images, with or without half-tones, with a view to their reproduction in a permanent form.

NOTE: In this definition the term telegraphy has the same general meaning as defined in the Convention. (RR)

Feeder Link. A radio link from an earth station at a given location to a space station, or vice versa, conveying information for a space radiocommunication service other than for the fixed-satellite service. The given location may be at a specified fixed point, or at any fixed point within specified areas. (RR)

Fixed-Satellite Service. A radiocommunication service between earth stations at given positions, when one or more [illegible] given position m[illegible] a specified fixed point or any fixe[illegible]int within specified areas; in some cases this service includes satellite-to-satellite links, which may also be operated in the inter-satellite service; the fixed-satellite service may also include feeder links for other space radiocommunication services. (RR)

Fixed Service. A radiocommunication service between specified fixed points (RR)

Fixed Station. A station in the fixed service. (RR)

Frequency-Shift Telegraphy. Telegraphy by frequency modulation in which the telegraph signal shifts the frequency of the carrier between predetermined values. (RR)

Frequency Tolerance. The maximum permissible departure by the centr frequency of the frequency band occupied by an emission from the assigne frequency or, by the characteristic fre quency of an emission from the ref erence frequency.

NOTE: The frequency tolerance is expresse in parts in 10^6 or in hertz. (RR)

Full Carrier Single-Sideband Emissio A single-sideband emission withou suppression of the carrier. (RR)

Frequency Hopping Systems. A fre quency hopping system is a sprea spectrum system in which the carrie is modulated with the coded informa tion in a conventional manner causin a conventional spreading of the RF en ergy about the carrier frequency. How ever, the frequency of the carrier is no fixed but changes at fixed interva under the direction of a pseudorandom coded sequence. The wide RF band width needed by such a system is no required by a spreading of the RF en ergy about the carrier but rather to a commodate the range of frequencies which the carrier frequency can hop.

Gain of an Antenna. The ratio, us ally expressed in decibels, of the pow required at the input of a loss free re erence antenna to the power suppli to the input of the given antenna produce, in a given direction, the sam field strength or the same power flu density at the same distance. When n specified otherwise, the gain refers the direction of maximum radiatio

The g[illegible]y be considered for a specified po[illegible]ion.

NOTE: Depending on the choice of the reference antenna a distinction is made between:

(1) Absolute or isotropic gain (Gi), when the reference antenna is an isotropic antenna isolated in space;

(2) Gain relative to a half-wave dipole (Gd), when the reference antenna is a half-wave dipole isolated in space whose equatorial plane contains the given direction;

(3) Gain relative to a short vertical antenna (Gv), when the reference antenna is a linear conductor, much shorter than one quarter of the wavelength, normal to the surface of a perfectly conducting plane which contains the given direction. (RR)

General Purpose Mobile Service. A mobile service that includes all mobile communications uses including those within the Aeronautical Mobile, Land Mobile, or the Maritime Mobile Services.

Geostationary Satellite. A geosynchronous satellite whose circular and direct orbit lies in the plane of the Earth's equator and which thus remains fixed relative to the Earth; by extension, a satellite which remains approximately fixed relative to the Earth. (RR)

Geostationary Satellite Orbit. The orbit in which a satellite must be placed to be a geostationary satellite. (RR)

Geosynchronous Satellite. An Earth satellite whose period of revolution is equal to the period of rotation of the Earth about its axis. (RR)

Harmful Interference[4]. Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with these [international] Radio Regulations. (RR)

Hybrid Spread Spectrum Systems. Hybrid spread spectrum systems are those which use combinations of two or more types of direct sequence, frequency hopping, time hopping and pulsed FM modulation in order to achieve their wide occupied bandwidths.

Inclination of an Orbit (of an earth satellite). The angle determined by the plane containing the orbit and the plane of the Earth's equator. (RR)

Individual Reception (in the broadc[illegible]ing-satellite service). The reception [illegible] emissions from a space station in the broadcasting-satellite service by simple domestic installations and in particular those possessing small antennae. (RR)

Industrial, Scientific and Medical (ISM) (of radio frequency energy) Applications. Operation of equipment or appliances designed to generate and use locally radio-frequency energy for industrial, scientific, medical, domestic or similar purposes, excluding applications in the field of telecommunications. (RR)

Instrument Landing System (ILS). A radionavigation system which provides aircraft with horizontal and vertical guidance just before and during landing and, at certain fixed points, indicates the distance to the reference point of landing. (RR)

Instrument Landing System Glide Path. A system of vertical guidance embodied in the instrument landing system which indicates the vertical deviation of the aircraft from its optimum path of descent. (RR)

Instrument Landing System Localizer. A system of horizontal guidance embodied in the instrument landing system which indicates the horizontal deviation of the aircraft from its optimum path of descent along the axis of the runway. (RR)

Interference. The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy. (RR)

Inter-Satellite Service. A radiocommunication service providing links between artificial earth satellites. (RR)

Ionospheric Scatter. The propagation of radio waves by scattering as a result of irregularities or discontinuities in the ionization of the ionosphere. (RR)

Land Earth Station. An earth station in the fixed-satellite service or, in some cases, in the mobile-satellite service, located at a specified fixed point or within a specified area on land to provide a feeder link for the mobile-satellite service. (RR)

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[4] See Resolution 68 of the *Radio Regulations.*

earth station in the land mobile-satellite service capable of surface movement within the geographical limits of a country or continent. (RR)

Land Mobile-Satellite Service. A mobile-satellite service in which mobile earth stations are located on land. (RR)

Land Mobile Service. A mobile service between base stations and land mobile stations, or between land mobile stations. (RR)

Land Mobile Station. A mobile station in the land mobile service capable of surface movement within the geographical limits of a country or continent.

Land Station. A station in the mobile service not intended to be used while in motion. (RR)

Left-Hand (or Anti-Clockwise) Polarized Wave. An elliptically or circularly-polarized wave, in fixed plane, normal to the direction of propagation, whilst looking in the direction of propagation, rotates with time in a left hand or anti-clockwise direction. (RR)

Line A. Begins at Aberdeen, Washington running by great circle arc to the intersection of 48° N., 120° W., thence along parallel 48° N., to the intersection of 95° W., thence by great circle arc through the southernmost point of Duluth, Minn., thence by great circle arc to 45° N., 85° W., thence southward along meridian 85° W., to its intersection with parallel 41° N., thence along parallel 41° N., to its intersection with meridian 82° W., thence by great circle arc through the southernmost point of Bangor, Maine, thence by great circle arc through the southernmost point of Searsport, Maine, at which point it terminates. (FCC)

Line B. Begins at Tofino, B.C., running by great circle arc to the intersection of 50° N., 125° W., thence along parallel 50° N., to the intersection of 90° W., thence by great circle arc to the intersection of 45° N., 79°30′ W., thence by great circle arc through the northernmost point of Drummondville, Quebec (Lat. 45°52′ N., Long 72°30′ W.), thence by great circle arc to 48°30′ N., 70° W., thence by great circle arc through the northernmost point of Compbellton, N.B., thence by great circle arc through the northernmost point

terminates. (FCC

Line C. Begins [illegible] intersection
70° N., 144° W., thence by great circl
arc to the intersection of 60° N., 14
W., thence by great circle arc so as
include all of the Alaskan Panhandle
(FCC)

Line D. Begins at the intersection
70° N., 138° W., thence by great circl
arc to the intersection of 61°20′ N., 1
W. (Burwash Landing), thence by grea
circle arc to the intersection of 60°
N., 135° W., thence by great circle ar
to the intersection of 56° N., 128° W
thence south along 128° meridian
Lat. 55° N., thence by great circle a
to the intersection of 54° N., 130°
thence by great circle arc to P
Clements, thence to the Pacific Oce
where it ends. (FCC)

Maritime Mobile-Satellite Service.
mobile-satellite service in which
bile earth stations are located on boa
ships; survival craft stations and em
gency position-indicating radiobeac
stations may also participate in th
service. (RR)

Maritime Mobile Service. A mob
service between coast stations and s
stations, or between ship stations,
between associated on-board comm
nication stations; survival craft st
tions and emergency position-indica
ing radiobeacon stations may also p
ticipate in this service. (RR)

*Maritime Radionavigation-Satell
Service.* A radionavigation-satell
service in which earth stations are
cated on board ships. (RR)

Maritime Radionavigation Service.
radionavigation service intended
the benefit and for the safe operati
of ships. (RR)

Marker Beacon. A transmitter in t
aeronautical radionavigation ser
which radiates vertically a distinc
pattern for providing position inform
tion to aircraft. (RR)

Mean Power (of a radio transmitt
The average power supplied to the
tenna transmission line by a transm
ter during an interval of time s
ciently long compared with the low
frequency encountered in the mod
tion taken under normal opera
conditions. (RR)

Meteorological Aids Service.
radiocommunication service used

trans[illegible] emission and/or reception of radio waves for specific telecommunication purposes.

NOTE: In these (international) Radio Regulations, unless otherwise stated, any radiocommunication service relates to terrestrial radiocommunication. (RR)

Radiodetermination. The determination of the position, velocity and/or other characteristics of an object, or the obtaining of information relating to these parameters, by means of the propagation properties of radio waves. (RR)

Radiodetermination-Satellite Service. A radiocommunication service for the purpose of radiodetermination involving the use of one or more space stations. This service may also include feeder links necessary for its own operation. (RR)

Radiodetermination Service. A radiocommunication service for the purpose of radiodetermination. (RR)

Radiodetermination Station. A station in the radiodetermination servlice. (RR)

Radio Direction-Finding. Radiodetermination using the reception of radio waves for the purpose of determining the direction of a station or object. (RR)

Radio Direction-Finding Station. A radiodetermination station using radio direction-finding. (RR)

Radiolocation. Radiodetermination used for purposes other than those of radionavigation. (RR)

Radiolocation Land Station. A station in the radiolocation service not intended to be used while in motion. (RR)

Radiolocation Mobil Station. A station in the radiolocation service intended to be used while in motion or during halts at unspecified points. (RR)

Radiolocation Service. A radiodetermination service for the purpose of radiolocation. (RR)

Radionavigation. Radiodetermination used for the purposes of navigation, including obstruction warning.

Radionavigation Land Station. A station in the radionavigation service not intended to be used while in motion. (RR)

Radionavigation Mobile Station. A station in the radionavigation service intended to be used while in motion or during halts at unspecified points. (RR)

Radionavigation-Satellite Service. [illegible] radiodetermination-satellite service used for the purpose of radionavigation. This service may also include feeder links necessary for its operation. (RR)

Radionavigation Service. A radiodetermination service for the purpose of radionavigation. (RR)

Radiosonde. An automatic radio transmitter in the meteorological aids service usually carried on an aircraft, free ballon, kite or parachute, and which transmits meteorological data. (RR)

Radiotelegram. A telegram, originating in or intended for a mobile station or a mobile earth station transmitted on all or part of its route over the radiocommunication channels of the mobile service or of the mobile-satellite service. (RR)

Radiotelemetry. Telemetry by means of radio waves. (RR)

Radiotelephone Call. A telephone call, originating in or intended for a mobile station or a mobile earth station, transmitted on all or part of its route over the radiocommunication channels of the mobile service or of the mobile-satellite service. (RR)

Radiotelex Call. A telex call, originating in or intended for a mobile station or a mobile earth station, transmitted on all or part of its route over the radiocommunication channels of the mobile service or the mobile-satellite service. (RR)

Radio Waves or Hertzian Waves. Electromagnetic waves of frequencies arbitrarily lower than 3,000 GHz, propagated in space without artificial guide. (RR)

Reduced Carrier Single-Sideband Emission. A single-sideband emission in which the degree of carrier suppession enables the carrier to be reconstrituted and to be used for demodulation. (RR)

Reference Frequency. A frequency having a fixed and specified position with respect to the assigned frequency. The displacement of this frequency with respect to the assigned frequency has the same absolute value and sign that the displacement of the characteristic frequency has with respect to the centre of the frequency band occupied by the emission. (RR)

Reflecting Satellite. A satellite intended to reflect radiocommunication signals. (RR)

Right-Hand (or Clockwise) Polarized Wave. An Elliptically or circularly-polarized wave, in which the electric field vector, observed in any fixed plane, normal to the direction of propagation, whilst looking in the direction of propagation, rotates with time in a right-hand or clockwise direction. (RR)

Safety Service. Any radiocommunication service used permanently or temporarily for the safeguarding of human life and property. (CONV)

Satellite. A body which revolves around another body of preponderant mass and which has a motion primarily and permanently determined by the force of attraction of that other body. (RR)

Satellite Link. A radio link between a transmitting earth station and a receiving earth station through one satellite. A satellite link comprises one up-link and one down-link. (RR)

Satellite Network. A satellite system or a part of a satellite system, consisting of only one satellite and the co-operating earth stations. (RR)

Satellite System. A space system using one or more artificial earth satellites. (RR)

Secondary Radar. A radiodetermination system based on the comparison of reference signals with radio signals retransmitted from the position to be determined. (RR)

Semi-Duplex Operation. A method which is simplex operation at one end of the circuit and duplex operation at the other.[3] (RR)

Ship Earth Station. A mobile earth station in the maritime mobile-satellite service located on board ship. (RR)

Ship Movement Service. A safety service in the maritime mobile service other than a port operations service, between coast stations and ship stations, or between ship stations, in which messages are restricted to those relating to the movement of ships. Messages which are of a public correspondence nature shall be excluded from this service. (RR)

Ship's Emergency Transmitter. A ship's transmitter to be used exclusively on a distress frequency [illegible]ress, urgency or safety purposes. (RR)

Ship Station. A mobile station in the maritime mobile service located on board a vessel which is not permanently moored, other than a survival craft station. (RR)

Simplex Operation. Operating method in which transmission is made possible alternatively in each direction of a telecommunication channel, for example, by means of manual control.[3] (RR)

Single-Sideband Emission. An amplitude modulated emission with one side-band only. (RR)

Spacecraft. A man-made vehicle which is intended to go beyond the major portion of the Earth's atmosphere. (RR)

Space Operation Service. A radiocommunication service concerned exclusively with the operation of spacecraft, in particular space tracking, space telemetry, and space telecommand.

NOTE: These functions will normally be provided within the service in which the space station is operating. (RR)

Space Radiocommunication. Any radiocommunication involving the use of one or more space stations or the use of one or more reflecting satellites or other objects in space. (RR)

Space Research Service. A radiocommunication service in which spacecraft or other objects in space are used for scientific or technological research purposes. (RR)

Space Station. A station located on an object which is beyond, is intended to go beyond, or has been beyond, the major portion of the Earth's atmosphere. (RR)

Space System. Any group of cooperating Earth stations and/or space stations employing space radiocommunication for specific purposes. (RR)

Space Telecommand. The use of radiocommunication for the transmission of signals to a space station to initiate, modify or terminate functions of equipment on a space object, incuding the space station. (RR)

Space Telemetry. The use of telemetry for transmission for a space station of results of measurements made in a space[illegible] ncluding those relating to the functioning of the spacecraft. (RR)

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[3] (See footnote under Duplex Operations.)

Space Tracking. Determination of the orbit, velocity or instantaneous position of an object in space by means of radiodetermination, excluding primary radar, for the purpose of following the movement of the object. (RR)

Special Service. A radiocommunication service, not otherwise defined in this Section, carried on exclusively for specific needs of general utility, and not open to public correspondence. (RR)

Spread Spectrum Systems. A spread spectrum system is an information bearing communications system in which: (1) Information is conveyed by modulation of a carrier by some conventional means, (2) the bandwidth is deliberately widened by means of a spreading function over that which would be needed to transmit the information alone. (In some spread spectrum systems, a portion of the information being conveyed by the system may be contained in the spreading function.)

Spurious Emission. Emission on a frequency or frequencies which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions. (RR)

Standard Frequency and Time Signal-Satellite Service. A radiocommunication service using space stations on earth satellites for the same purposes as those of the standard frequency and time signal service.

NOTE: This service may also include feeder links necessary for its operation. (RR)

Standard Frequency and Time Signal Service. A radiocommunication service for scientific, technical and other purposes, providing the transmission of specified frequencies, time signals, or both, of stated high precision, intended for general reception. (RR)

Standard Frequency and Time Signal Station. A station in the standard frequency and time signal service. (RR)

Station. One or more transmitter[illegible] receivers or a combination of transmitters and receivers, including the accessory equipment, necessary at one location for carrying on a radiocommunication service, or the radio astronomy service.

NOTE: Each station shall be classified by the service in which it operates permanently or temporarily. (RR)

Suppressed Carrier Single-Sideband Emission. A single-sideband emission in which the carrier is virtually suppressed and not intended to be used for demodulation. (RR)

Survival Craft Station. A mobile station in the maritime mobile service or the aeronautical mobile service intended solely for survival purposes and located on any lifeboat, life-raft or other survival equipment. (RR)

Telecommand. The use of telecommunication for the transmission of signals to initiate, modify or terminate functions of equipment at a distance. (RR)

Telecommunication. Any transmission, emission or reception of signs, signals, writing, images and sounds or intelligence of any nature by wire, radio, optical or other electromagnetic systems. (CONV)

Telegram. Written matter intended to be transmitted by telegraphy for delivery to the addressee. This term also includes radiotelegrams unless otherwise specified.

NOTE: In this definition the term telegraphy has the same general meaning as defined in the Convention. (CONV)

Telegraphy. A form of telecommunication which is concerned in any process providing transmission and reproduction at a distance of documentary matter, such as written or printed matter or fixed images, or the reproduction at a distance of any kind of information in such a form. For the purposes of the [International] Radio Regulations, unless otherwise specified therein, telegraphy shall mean a form of telecommunication for the transmission of written matter by the use of a signal code.[4] (RR)

Telemetry. The use of telecommunication for automatical indicating or recording measurements at a distance from the measuring instrument. (RR)

Telephony. A form of telecommunication set up for the transmission of speech or, in some cases, other sounds.[4] (RR)

Television. A form of telecommunication for the transmission of transient images of fixed or moving objects. (RR)

Terrestrial Radiocommunication. Any radiocommunication other than space radiocommunication or radio astronomy. (RR)

Terrestrial Station. A station effecting terrestrial radiocommunication.

NOTE: In these [International Radio] Regulations, unless otherwise stated, any station is a terrestrial station. (RR)

Time Hopping Systems. A time hopping system is a spread spectrum system in which the period and duty cycle of a pulsed RF carrier are varied in a pseudorandom manner under the control of a coded sequence. Time hopping is often used effectively with frequency hopping to form a hybrid time-division, multiple-access (TDMA) spread spectrum system.

Transponder. A transmitter-receiver facility the function of which is to transmit signals automatically when the proper interrogation is received. (FCC)

Tropospheric Scatter. The propagation of radio waves by scattering as a result of irregularities or discontinuities in the physical properties of the troposphere. (RR)

Unwanted Emissions. Consist of spurious emissions and out-of-band emissions. (RR)

[49 FR 2368, Jan. 19, 1984, as amended at 50 FR 25239, June 18, 1985; 51 FR 37399, Oct. 22, 1986; 52 FR 7417, Mar. 11, 1987; 54 FR 49980, Dec. 4, 1990; 55 FR 28761, July 13, 1990; 56 FR 42703, Aug. 29, 1991; 58 FR 68058, Dec. 23, 1993]

Subpart B—Allocation, Assignment, and Use of Radio Frequencies

SOURCE: 49 FR 2373, Jan. 19, 1984, unless otherwise noted.

§ 2.100 Internatio[illegible]egulations in force.

The international *Radio Regulations* (Geneva, 1982), became effective internationally on 1 January 1982, and nationally on September 6, 1983. They are incorporated to the extent practicable in this part.

§ 2.101 Nomenclature of frequencies.

Band No.	Frequency subdivision	Frequency range
4	VLF (very low frequency).	Below 30 kHz.
5	LF (low frequency)	30 to 300 kHz.
6	MF (medium frequency)	300 to 3000 kHz
7	HF (high frequency)	3 to 30 MHz
8	VHF (very high frequency)	30 to 300 MHz
9	UHF (ultra high frequency)	300 to 3000 MHz.
10	SHF (super high frequency).	3 to 30 GHz
11	EHF (extremely high frequency)	30 to 300 GHz
12		300 to 3000 GHz.

§ 2.102 Assignment of frequencies.

(a) Except as otherwise provided i this section, the assignment of frequencies and bands of frequencies to al stations and classes of stations and the licensing and authorizing of the use o all such frequencies between 9 kHz and 400 GHz, and the actual use of such frequencies for radiocommunication o for any other purpose, including the transfer of energy by radio, shall be i accordance with the Table of Frequency Allocations in § 2.106.

(b) On the condition that harmful interference will not be caused to services operating in accordance with th Table of Frequency Allocations the following exceptions to paragraph (a) o this section may be authorized:

(1) In individual cases the Commission may, without rule making proceedings, authorize on a temporar basis only, the use of frequencies not i accordance with the Table of Frequency Allocations for projects o short duration or emergencies wher the Commission finds that importan or exceptional circumstances requir such utilization. Such authorization are not intended to develop a service t be operated on frequencies other tha those allocated such service.

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[4] (See footnote under Harmful Interference)

International table			United States table		FCC use designators	
			Government	Non-Government		
Region 1—allocation GHz	Region 2—allocation GHz	Region 3—allocation GHz	Allocation GHz	Allocation GHz	Rule part(s)	Special-use frequencies
(1)	(2)	(3)	(4)	(5)	(6)	(7)
FIXED. MOBILE. RADIOLOCATION. Amateur. 828	RADIOLOCATION. Amateur. 828 829	FIXED. MOBILE. RADIOLOCATION. Amateur. 828	RADIOLOCATION. 828 US58 US108 G32	Amateur. Radiolocation. 828 US58 US108 NG42	Amateur (97). Private Land Mobile (90).	
10.45–10.5	RADIOLOCATION. Amateur. Amateur-Satellite. 830		10.45–10.50 RADIOLOCATION. US58 US108 G32	10.45–10.50 Amateur. Amateur-Satellite. Radiolocation. US58 US108 NG42 NG134	Amateur (97). Private Land Mobile (90).	
10.50–10.55 FIXED. MOBILE. Radiolocation.	10.50–10.55 FIXED. MOBILE. RADIOLOCATION.		10.50–10.55 RADIOLOCATION. US59	10.50–10.55 RADIOLOCATION. US59	PRIVATE LAND MOBILE (90).	
10.55–10.60	FIXED. MOBILE except aeronautical mobile. Radiolocation.		10.55–10.60	10.55–10.60 FIXED.	DOMESTIC PUBLIC FIXED (21). PRIVATE OPERATIONAL–FIXED MICROWAVE (94)	
10.60–10.68	EARTH EXPLORATION-SATELLITE (passive). FIXED. MOBILE except aeronautical mobile. RADIO ASTRONOMY. SPACE RESEARCH (passive). Radiolocation. 831 832		10.60–10.68 EARTH-EXPLORATION-SATELLITE (passive). SPACE REASEARCH (passive). US265 US277	10.60–10.68 EARTH EXPLORATION-SATELLITE (passive). FIXED. SPACE RESEARCH (passive). US265 US277	DOMESTIC PUBLIC FIXED (21). PRIVATE OPERATIONAL–FIXED MICROWAVE (94)	
10.68–10.70	EARTH EXPLORATION-STATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive). 833 834		10.68–10.70 EARTH-EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive). US74 US246	10.68–10.70 EARTH EXPLORATION-STATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive). US74 US246		
10.7–11.7 FIXED. FIXED-SATELLITE (space-to Earth). (Earth-to-space) 835 MOBILE except aeronautical mobile. 792A	10.7–11.7 FIXED. FIXED-SATELLITE (space-to-Earth). MOBILE except aeronautical mobile. 792A		10.7–11.7 US211	10.7–11.7 FIXED. FIXED-SATELLITE (space-to-Earth). 792A US211 NG41 NG104	DOMESTIC PUBLIC FIXED (21). PRIVATE OPERATIONAL–FIXED MICROWAVE (94)	
11.7–12.5 FIXED. BROADCASTING. BROADCASTING-SATELLITE. Mobile except aeronautical mobile. 838	11.7–12.1 FIXED 837 FIXED-SATELLITE (space-to Earth). Mobile except aeronautical mobile. 836 839	11.7–12–2 FIXED. MOBILE except aeronautical mobile. BROADCASTING. BROADCASTING-SATELLITE. 838	11.7–12.2 839	11.7–12.2 FIXED.SATELLITE (space-to Earth). Mobile except aeronautical mobile. 837 839 NG143 NG145	DOMESTIC PUBLIC FIXED (21). SATELLITE COMMUNICATION (25).	
	12.1–12.2 FIXED-SATELLITE (space-to-Earth). 836 839 842.					
		12.2–12.5 FIXED. MOBILE except aeronautical mobile. BROADCASTING.	12.2–12.7	12.2–12.7 FIXED. BROADCASTING-SATELLITE.	INTERNATIONAL PUBLIC (23). PRIVATE OPERATIONAL–FIXED MICROWAVE (94). DIRECT BROADCAST SATELLITE SERVICE (100).	

Morocco, Mauritania, Mongolia, Nigeria, Oman, Pakistan, the Philippines, Poland, Qatar, the Syria, German Democratic Republic, Roumania, Singapore, Somalia, Sri Lanka, Czechoslovakia, Tunisia, Thailand, the U.S.S.R., Yemen A.R., Yemen (P.D.R. of), Yugoslavia, Zaire and Zambia, the band 2 690—2 700 MHz is also allocated to the fixed and mobile, except aeronautical mobile, services on a primary basis. Such use is limited to equipment in operation by 1 January 1985.

770 In the band 2 700—2 900 MHz, ground-based radars used for meteorological purposes are authorized to operate on a basis of equality with stations of the aeronautical radionavigation service.

771 *Additional allocation:* In Canada, the band 2 850—2 900 MHz is also allocated to the maritime radionavigation service, on a primary basis, for use by shore-based radars.

772 In the band 2900-3100 MHz, the use of the shipborne interrogator transponder system (SIT) shall be confined to the sub-band 2930-2950 MHz.

773 The use of the band 2 900—3 100 MHz by the aeronautical radionavigation service is limited to ground based radars.

775A In the bands 2900-3100 MHz and 9300-9500 MHz, the response from radar transponders shall not be capable of being confused with the response from radar beacons (racons) and shall not cause interference for ship or aeronautical radars in the radionavigation service, having regard, however, to No. 347 of these Regulations.

777 *Additional location:* In Bulgaria, Canada, Cuba, Hungary, Mongolia, Poland, the German Democratic Republic, Roumania, Czechoslovakia and the U.S.S.R., the band 3 100—3 300 MHz is also allocated to the radionavigation service on a primary basis.

778 In making assignments to stations of other service, administrations are urged to take all practicable steps to protect the spectral line observations of the radio astronomy service from harmful interference in the bands 3 260—3 267 MHz, 3 332—3 339 MHz, 3 345.8—3 352.5 MHz and 4 825—4 835 MHz. Emissions from space or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 343 and 344 and Article 36).

779 *Additional allocation:* In Afghanistan, Saudi Arabia, Bahrain, Bangladesh, China, the Congo, the United Arab Emirates, India, Indonesia, Iran, Iraq, Israel, Japan, Kuwait, Lebanon, Libya, Malaysia, Oman, Pakistan, Qatar, Syria, Singapore, Sri Lanka and Thailand, the band 3 300—3 400 MHz is also allocated to the fixed and mobile services on a primary basis. The countries bordering the Mediterranean shall not claim protection for their fixed and mobile services from the radiolocation service.

780 *Additional location:* In Bulgaria, Cuba, Hungary, Mongolia, Poland, the German Democratic Republic, Roumania, Czechoslovakia and the U.S.S.R., the band 3 300—3 400 MHz is also allocated to the radionavigation service on a primary basis.

781 *Additional allocation:* In the Federal Republic of Germany, Israel and the United Kingdom, the band 3 400—3 475 MHz is also allocated to the amateur service on a secondary basis.

782 *Different category of service:* In Austria, the allocation of the band 3 400—3 500 MHz to the radiolocation service is on a primary basis (see No. 425), subject to the agreement of the administrations of the following countries: Hungary, Italy, the German Democratic Republic, Czechoslovakia and Yugoslavia. Such use is limited to ground-based stations. However, this administration is urged to cease operations by 1985. After this date this administration shall take all practicable steps to protect the fixed-satellite service and coordination requirements shall not be imposed on the fixed-satellite service.

783 *Different category of service:* In Indonesia, Japan, Pakistan and Thailand, the allocation of the band 3 400—3 500 MHz to the mobile, except aeronautical mobile, service is on a primary basis (see No. 425).

784 In Regions 2 and 3, in the band 3 400—3 600 MHz the radiolocation service is allocated on a primary basis. However, all administrations operating radiolocation systems in this band are urged to cease operations by 1985. Thereafter, administrations shall take all practicable steps to protect the fixed satellite service and coordination requirements shall not be imposed on the fixed-satellite service

785 In Denmark, Norway and the United Kingdom, the fixed, radiolocation and fixed-satellite services operate on a basis of equality of rights in the band 3 400—3 600 MHz. However, these administrations operating radiolocation systems in this band are urged to cease operations by 1985. After this date these administrations shall take all practicable steps to protect the fixed-satellite service and coordination requirements shall not be imposed on the fixed-satellite service.

786 In Japan, in the band 3 620—3 700 MHz, the radiolocation service is excluded.

787 *Additional allocation:* In New Zealand, the band 3 700—3 770 MHz is also allocated to the radiolocation service on a secondary basis.

788 *Additional allocation:* In the Federal Republic of Germany, Denmark, Norway and Sweden, the band 4 200—4 210 MHz is also allocated to the fixed service on a secondary basis.

789 Use of the band 4 200—4 400 MHz by the aeronautical radionavigation service is reserved exclusively for radio altimeters installed on board aircraft and for the associated transponders on the ground. However, passive sensing in the Earth exploration-satellite and space research services may be authorized in this band on a secondary basis (no protection is provided by the radio altimeters).

790 *Additional allocation:* In China, Iran, Libya, the Philippines and Sri Lanka, the band 4 200—4 400 MHz is also allocated to the fixed service on a secondary basis.

791 The standard frequency and time signal-satellite service may be authorized to use the frequency 4 202 MHz for space-to-Earth transmissions and the frequency 6 427 MHz for Earth-to-space transmissions. Such transmissions shall be confined within the limits of ±2 MHz of these frequencies and shall be subject to agreement obtained under the procedure set forth in Article 14.

792A The use of the bands 4 500-4 800 MHz, 6 725-7 025 MHz, 10.7-10.95 GHz, 11.2-11.45 GHz and 12.75-13.25 GHz by the fixed-satellite service shall be in accordance with the provisions of Appendix 30B.

793 In the bands 4 825—4 835 MHz and 4 950—4 990 MHz, the allocation to the mobile service is restricted to the mobile, except aeronautical mobile, service.

794 *Different category of service:* In Argentina, Australia and Canada, the allocation of the bands 4 825—4 835 MHz and 4 950—4 990 MHz to the radim astronomy service is on a primary basis. In making assignments to stations of other services to which these bands are allocated, administratiмns are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from space or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 343 and 344 and Article 36).

795 In making assignments to stations of other services to which the band 4 990—5 000 MHz is allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from space or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 343 and 344 and Article 36).

796 The band 5 000—5 250 MHz is to be used for the operatimn of the International standard system (microwave landing system) for precision approach and landing. The requirements of this system shall take precedence over other uses of this band.

797 The bands 5 000—5 250 MHz, and 15.4—15.7 GHz are also allocated to the fixed-satellite service and the inter-satellite service, for connection between one or more earth stations at specified fixed points on the Earth and space stations, when thes services are used in conjunction with th aeronautical radionavigation and/or aer nautical mobile (R) service. Such use sh be subject to agreement obtained under th procedure set forth in Article 14.

797A *Additional allocation:* In the coun tries listed in Nos. 733B and 753C, and sub ject to agreement obtained under the pro dure set forth in Article 14, and band 51 5216 MHz is also allocated to the radiodete mination-satellite service (space-to-Ear on a primary basis. In Region 2, the band also allocated to the radiodetermination-sa ellite service (space-to-Earth) on a prim basis. In regions 1 and 3, except those cou tries listed in Nos. 733B and 753C, the ban is also allocated to the radiodeterminati satellite service (space-to-Earth) on a se ondary basis. The use by the radiodeterm ation-satellite service is limited to feed links in conjunction with the radiodetern ation-satellite service operating in the ba 1610-1626.5 MHz and/or 2483.5-2500 M The total power flux-density at the Earth surface shall in no case exceed −159 dBW m² in any 4 kHz band for all angles of arr al.

797B *Additional allocation:* In the Fed al Republic of Germany, Austria, Denm Spain, France, Finland, Israel, Italy, Jord Morocco, Norway, the Netherlands, Pa stan, the United Kingdom, Sweden, Switz land, Syria and Tunisia, the band 5150-52 MHz is also allocated to the mobile serv on a primary basis, subject to the agree obtained under the procedure set fort Article 14.

798 *Additional allocation:* In Austr Bulgaria, Hungary, Libya, Mongol Poland, the German Democratic Repub Roumania, Czechoslovakia and the U.S.S. the band 5 250—5 350 MHz is also alloc to the radionavigation service on a prim basis.

799 The use of the band 5 350—5 4 MHz by the aeronautical radionavigati service is limited to airborne radars and sociated airborne beacons

800 *Additional allocation:* In Afgh stan, Austria, Bulgaria, Hungary, Iran, M golia, Poland, the German Democratic public, Roumania, Czechoslovakia and U.S.S.R., the band 5 470—5 650 MHz is allocated to the aeronautical radionav tion service on a primary basis.

801 *Additional allocation:* In the Uni Kingdom, the band 5 470—5 850 MHz is allocated to the land mobile service on a s ondary basis. The power limits specifi Nos. 2502, 2505, 2506 and 2507 shall app the band 5 725—5 850 MHz.

802 Between 5 600 MHz and 5 650 M ground-based radars used for meteorol purposes are authorized to operate

shall b[illegible]ondary basis to stations in the non[illegible]rnment land mobile service and shall be subject to adjustment or removal from the bands 890–902 MHz, 928–932 MHz and 935–941 MHz at the request of the FCC.

US117 In the band 406.1–410 MHz, all new authorizations will be limited to a maximum 7 watts per kHz of necessary bandwidth; existing authorizations as of November 30, 1970 exceeding this power are permitted to continue in use.

New authorizations in this band stations, other than mobile stations, within the following areas are subject to prior coordination by the applicant through the Electromagnetic Spectrum Management Unit, National Science Foundation, Washington, D.C. 20550, (202–357–9696):

Arecibo Observatory:

Rectangle between latitudes 17°30′N. and 19°00′N. and between longitudes 65°10′ W. and 68°00′W.

Owens Valley Radio Observatory:

Two contiguous rectangles, one between latitudes 36°N. and 37°N. and longitudes 117°40′W. and 118°30′W. and the second between latitudes 37°N. and 38°N. and longitudes 118°W. and 118°50′W.

Sagamore Hill Radio Observatory:

Rectangle between latitudes 42°10′N. and 43°00′N. and longitudes 70°31′W. and 71°31′W.

Table Mountain Solar Observatory (NOAA), Boulder, Colorado (407–409 MHz only):

Rectangle between latitudes 39°30′N. and 40°30′N. and longitudes 104°30′W. and 106°00′W. or the Continental Divide whichever is farther east.

The non-Government use of this band is limited to the radio astronomy service and as provided by footnote US13.

US201 In the band 460–470 MHz, space stations in the earth exploration-satellite service may be authorized for space-to-earth transmissions on a secondary basis with respect to the fixed and mobile services. When operating in the meteorological-satellite service, such stations shall be protected from harmful interference from other applications of the earth exploration-satellite service. The power flux produced at the earth's surface by any space station in this band shall not exceed −152 dBW/m¾ kHz.

US203 Radio astronomy observations of the formaldehyde line frequencies 4825–4835 MHz and 14.470–14.500 GHz may be made at certain radio astronomy observatories as indicated below:

BANDS TO BE OBSERVED

4 GHz	14 GHz	Observatory
X	....	National Astronomy and Ionosphere Center, Arecibo, Puerto Rico.
X	X	National Radio Astronomy Observatory, Green Bank, W. Va.
X	X	National Radio Astronomy Observatory, Socorro, New Mexico.
X	X	Hat Creek Observatory (U of Calif.), Hat Creek, Cal.
X	X	Haystack Radio Observatory (MIT-Lincoln Lab), Tyngsboro, Mass.
X	X	Owens Vally Radio Observatory (Cal. Tech.), Big Pine, Cal.
....	X	Five College Radio Astronomy Observatory Quabbin Reservoir (near Amherst), Massachusetts.

Every practicable effort will be made to avoid the assignment of frequencies to stations in the fixed or mobile services in these bands. Should such assignments result in harmful interference to these observations, the situation will be remedied to the extent practicable.

US205 Tropospheric scatter systems are prohibited in the band 2500–2690 MHz.

US208 Planning and use of the band 1559–1626.5 MHz necessitate the development of technical and/or operational sharing criteria to ensure the maximum degree of electromagnetic compatibility with existing and planned systems within the band.

US209 The use of frequencies 460.6625, 460.6875, 460.7125, 460.7375, 460.7625, 460.7875, 460.8125, 460.8375, 460.8625, 465.6625, 465.6875, 465.7125, 465.7375, 465.7625, 465.7875, 465.8125, 465.8375, and 465.8625 MHz may be authorized, with 100 mW or less output power, to Government and non-Government radio stations for one-way, non-voice bio-medical telemetry operations in hospitals, or medical or convalescent centers.

US210 Use of frequencies in the bands 40.66–40.70 and 216–220 MHz may be authorized to Government and non-Government stations on a secondary basis for the tracking of, and telemetering of scientific data from, ocean buoys and wildlife. Airborne wildlife telemetry in the 216–220 MHz band will be limited to the 216.0–216.1 MHz portion of the band. Operation in these two bands is subject to the technical standards specified in: (a) Section 8.2.42 of the NTIA Manual for Government use, or (b) Section 5.108 of the Commission's Rules for non-Government use.

US211 In the bands 1670–1690, 5000–5250 MHz and 10.7–11.7, 15.1365–15.35, 15.4–15.7, 22.5–22.55, 24–24.05, 31.0–31.3, 31.8–32.0, 40.5–42.5, 84–86, 102–105, 116–126, 151–164, 176.5–182, 185–190, 231–235, 252–265 GHz, applicants for airborne or space station assignments are urged to take all practicable steps to protect radio astronomy observations in the adjacent lands from harmful interference; however, US74 applies.

US212 In the State of Alaska, the carrier frequency 5167.5 kHz (assigned frequency 5168.9 kHz) is designated for emergency communications. This frequency may also be

used in the Alaska-Private Fixed Service for calling and listening, but only for establishing communications before switching to another frequency. The maximum power is limited to 150 watts peak envelope power (PEP).

US213 The frequency 122.925 MHz is for use only for communications with or between aircraft when coordinating natural resources programs of Federal or State natural resources, agencies, including forestry management and fire suppression, fish and game management and protection and environmental monitoring and protection.

US214 The frequency 157.1 MHz is the primary frequency for liaison communications between ship stations and stations of the United States Coast Guard.

US215 Emissions from microwave ovens manufactured on and after January 1, 1980, for operation on the frequency 915 MHz must be confined within the band 902–928 MHz. Emissions from microwave ovens manufactured prior to January 1, 1980, for operation on the frequency 915 MHz must be confined within the band 902–940 MHz. Radiocommunications services operating in the band 928–940 MHz must accept any harmful interference from the operation of microwave ovens manufactured before January 1, 1980.

US216 The frequencies 150.775 and 150.790, and the bands 152–152.0150, 163.2375–163.2625, 462.9375–463.1875 and 467.9375–468.1875 MHz are authorized for Governmelt/non-Governmelt operations in medical radio commulications systems.

US217 Pulse-ranging radimlocation systems may be authorized for Governmelt and non-Government use in the 420–450 MHz band along the shorelines of Alaska and the contiguous 48 states. Spread spectrum radiolocation systems may be authorized in the 420–435 MHz portion of the band for operation within the contiguous 48 States and Alaska. Authorizations will be eranted on a case-by-case basis; howeter, operations proposed to be located within the zones set forth in US228 should not expect tm be accommodated. All stations operating in accordance with this provision will be secondary to stations operating in accordance with the Table of Frequency Allocations.

US218 The band 902–928 MHz is available for Location and Monitoring Service (LMS) systems subject to not causing harmful interference to the operation of all Government stations authorized in these bands. These systems must tolerate interference from the operation of industrial, scientific, and medical (ISM) devices and the operation of Government stations authorized in these bands.

US219 In the band 2025–2110 MHz Government Earth resources satellite Earth stations in the Earth exploration-satellite service may be authorized to use the frequency 2106.4 MHz for Earth-to-space transmission for tracking, telen[illegible]nd telecommand the sites listed be[illegible] Such transmissio shall not cause harmful interference to no Government operations:

Sioux Falls, South Dakota, 43°32′03.1″ N. 96°45′42.8″ W.

Fairbanks, Alaska, 64°58′36.6″ N., 147°30′54. W.

US220 The frequencies 36.25 and 41.71 M may be authorized to Government statio and non-Government stations in the petr leum radio service, for oil spill containme and cleanup operations. The use of these fr quencies for oil spill containment or cleanu operations is limited to the inland and coastal waterway regions.

US221 In the 525–535 kHz band, the mobi service is limited to distribution of publ service information from Travelers Informa tion Stations operating on 530 kHz.

US222 In the band 2025–2035 MHz ge stationary operational environmental sat ellite Earth stations in the space resear and Earth exploration-satellite services m be authorized on a coequal basis for Eart to-space transmissions for tracking, teler etry, and telecommand at the sites list below:

Wallops Is., Va. 37°50′48″ N., 75°27′33″ W.
Seattle, Wash. 47°34′15″ N., 122°33′10″ W.
Honolulu, Hawaii 21°21′12″N., 157°52′36″W.

US223 Within 75 miles of the Unit States/Canada border on the Great Lake the St. Lawrence Seaway, and the Pug Sound and the Strait of Juan de Fuca and i approaches, use of coast transmit frequen 162.025 MHz and ship station transmit fr quency 157.425 MHz (VHF maritime mobi service Channel 88) may be authorized f use by the maritime service for public co respondence.

US224 Government systems utilizin spread spectrum techniques for terrestri communication, navigation and identific tion may be authorized to operate in t band 960–1215 MHz on the condition th harmful interference will not be caused the aeronautical radionavigation servic These systems will be handled on a case-b case basis. Such systems shall be subject a review at the national level for operation requirements and electromagnetic compa ibility prior to development, procurement modification.

US225 In addition to its present Gover ment use, the frequency band 510–525 kHz available to Government and non-Gover ment aeronautical radionavigation statio inland of the Territorial Base Line as coord nated with the military services. In additio the frequency 510 kHz is available for no Government ship-helicopter operations wh beyond 100 nautical miles from shore and r quired for aeronautical radionavigation.

US226 In the State of Hawaii, stations the aeronautical radionavigation servic geostatio[illegible]tellite systems, including satellite links between land earth stations.

US327 The band 2310–2360 MHz is allocated to the broadcasting-satellite service (sound) and complementary terrestrial broadcasting service on a primary basis. Such use is limited to digital audio broadcasting and is subject to the provisions of Resolution 528.

US328 In the band 2310–2360 MHz, the mobile and radiolocation services are allocated on a primary basis until 1 January 1997 or until a broadcasting-satellite (sound) service has been brought into use in such a manner as to affect or be affected by the mobile and radiolocation services in those service areas, whichever is later. The broadcasting-satellite (sound) service during implementation should also take cognizance of the expendable and reusable launch vehicle frequencies 2312.5, 2332.5, and 2352.5 MHz, to minimize the impact on this mobile service use to the extent possible.

US334 In the band 17.8–20.2 GHz, Government space stations and associated earth stations in the fixed satellite (space-to-Earth) service may be authorized on a primary basis. For a Government geostationary satellite network to operate on a primary basis, the space station shall be located outside the arc measured from East to West, 70°W to 120°W. Coordination between Government fixed-satellite systems and non-Government systems operating in accordance with the United States Table of Frequency Allocations is required.

NON-GOVERNMENT (NG) FOOTNOTES

(These footnotes, each consisting of the letters "NG" followed by one or more digits, denote stipulations applicable only to the non-Government.)

NG2 Facsimile broadcasting stations may be authorized in the band 88–108 MHz.

NG3 Control stations in the domestic public mobile radio service may be authorized frequencies in the band 72–73 and 75.4–76 MHz on the condition that harmful interference will not be caused to operational fixed stations.

NG4 The use of the frequencies in the band 152.84–153.38 MHz may be authorized, in any area, to remote pickup broadcast base and mobile stations on the condition that harmful interference will not be caused to stations operating in accordance with the Table of Frequency Allocations.

NG6 Stations in the public safety radio services authorized as of June 30, 1958, to use frequencies in the band 159.51–161.79 MHz in areas other than Puerto Rico and the Virgin Islands may continue such operation, including expansion of existing systems, on the condition that harmful interference will not be caused to stations in the services to which these bands are allocated. In Puerto Rico and the Virgin Islands this authority is limited to frequencies in the band 160.05–161.37 MHz. No new public radio service system will be authorized to operate on these frequencies.

NG12 Frequencies in the bands 454.40–455 MHz and 459.40–460 MHz may be assigned to domestic public land and mobile stations to provide a two-way air-ground public radiotelephone service.

NG17 Stations in the land transportation radio services authorized as of May 15, 1958 to operate on the frequency 161.61 MHz may, upon proper application, continue to be authorized for such operation, including expansion of existing systems, on the condition that harmful interference will not be caused to the operation of any authorized station in the maritime mobile service. No new land transportation radio service system will be authorized to operate on 161.61 MHz.

NG19 Fixed stations associated with the maritime mobile service may be authorized, for purposes of communication with coast stations, to use frequencies assignable to ship stations in this band on the condition that harmful interference will not be caused to services operating in accordance with the Table of Frequency Allocations.

NG23 Frequencies in the band 2100–2200 MHz may also be assigned to stations in the international fixed public radio service located south of 25°30 north latitutde in the State of Florida and in U.S. Possessions in the Caribbean area, provided, however, no new assignments in the band 2150–2162 MHz will be made to such stations after February 25, 1974.

NG28 The frequency band 160.86–161.40 MHz is available for assignment to remote pickup base and remote pickup mobile stations in Puerto Rico and the Virgin Islands only on a shared basis with the land transportation radio service.

NG30 Stations in the international fixed public radiocommunication service in Florida, south of 25°30 north latitude, may be authorized to use frequencies in the band 716–890 MHz on the condition that harmful interference will not be caused to the broadcasting service of any country. This is an interim allocation the termination of which will later be specified by the Commission when it is determined that equipments are generally available for use in bands allocated internationally to the fixed service.

NG31 Stations in the Rural Radio Service licensed for Basic Exchange Telecommunications Radio Service may be authorized to use some frequencies in the bands 816–820 MHz (fixed subscriber) and 861–865 MHz (central office or base), on a co-primary basis with private land mobile radio licensees, pursuant to part 22 subpart H.

NG41 Frequencies in the bands 3700–4200 MHz, 5925–6425 MHz, and 10.7–11.7 GHz may also be assigned to stations in the international fixed public and international control services located in U.S. Possessions in the Caribbean area.

NG42 Non-Government stations in the radiolocation service shall not cause harmful interference to the amateur service.

NG43 Fixed stations in the domestic public radio services in Alaska, south of 56° north latitude and east of 134° west longitude, may be authorized to use frequencies in the band 800–830 MHz, on the condition that harmful interference will not be caused to the broadcasting service of any country.

NG47 In Alaska frequencies between the band 2655–2690 MHz are not available for assignment to terrestrial stations.

NG49 The following frequencies may be authorized for mobile operations in the Manufacturers Radio Service subject to the condition that no interference is caused to the reception of television stations operating on channels 4 and 5 and that their use is limited to a manufacturing facility:

MHz	
72.02	72.22
72.04	72.24
72.06	72.26
72.08	72.28
72.10	72.30
72.12	72.32
72.14	72.34
72.16	72.36
72.18	72.38
72.20	72.40

Further, the following frequencies may be authorized for mobile operations in the Special Industrial Radio Service, Manufacturers Radio Service, Railroad Radio Service and Forest Products Radio Service subject to the condition that no interference is caused to the reception of television stations operating on channels 4 and 5; and that their use is limited to a railroad yard, manufacturing plant, logging site, mill, or similar industrial facility.

MHz	
72.44	75.44
72.48	75.48
72.52	75.52
72.56	75.56
72.60	75.60

NG51 In Puerto Rico and the Virgin Islands only, the bands 150.8–150.98 MHz and 150.98–151.49 MHz are allocated exclusively to the business radio service.

NG53 In the band 12.7–13.15 GHz, television pickup stations and CARS pickup stations shall be assigned channels on a coequal basis and shall operate on a secondary basis to fixed stations operating in accordance with the Table of Frequency Allocations. In the 13.15–13.20 GHz band television pickup stations a[illegible] pickup statio shall be assigned on [illegible]clusive basis in t top one hundred markets, as set out in Se tion 76.51.

NG56 In the bands 72.0–73.0 and 75.4–7 MHz, the use of mobile radio remote contr of models is on a secondary basis to all oth fixed and mobile operations. Such operatio are subject to the condition that inte ference will not be caused to common carri domestic public stations, to remote contr of industrial equipment operating in the 7 76 MHz band, or to the reception of televisi signal on channels 4 (66–72 MHz) or 5 (76– MHz). Television interference shall be co sidered to occur whenever reception of reg larly used television signals is impaired destroyed, regardless of the strength of t television signal or the distance to the tel vision station.

NG59 The frequencies 37.60 and 37.85 M may be authorized only for use by base, m bile, and operational fixed stations partic pating in an interconnected or coordinat power service utility system.

NG63 Television Broadcast translator st tions holding valid licenses on November 1971, to operate in the frequency band 806–8 MHz (channels 70–83), may continue to ope ate in this band, pursuant to periodic licen renewals, on a secondary basis to the la mobile radio service.

NG66 The frequency band 470–512 MHz allocated for use in the broadcasting a land mobile radio services. In the land m bile services it is available for assignment the domestic public, public safety, indu trial, and land transportation radio servic at, or in the vicinity of 13 urbanized areas the United States, as set forth in the tab below. Additionally, in the land mobile ser ices, TV Channel 16 is available for assig ment in the public safety radio services or in the vicinity of Los Angeles. Such use the land mobile services is subject to th conditions set forth in parts 22 and 90 of th chapter, CFR 47.

Urbanized area	TV channel
New York-Northeastern New Jersey	14, 1
Los Angeles	14, 2
Chicago-Northwestern Indiana	14, 1
Philadelphia, PA-New Jersey	19, 2
Detroit, Michigan	15, 1
San Francisco-Oakland, California	16, 1
Boston, Mass	14, 1
Washington, D.C.-Maryland-Virginia	17, 1
Pittsburgh, PA	14, 1
Cleveland, Ohio	14, 1
Miami, Florida	1
Houston, Texas	1
Dallas, Texas	1

NG70 In Puerto Rico and the Virgin I lands only, the bands 159.240–159.435 a

160.4[illegible] MHz are also available for assignment to base stations and mobile stations in the special industrial radio service.

NG101 The use of the band 2500–2690 MHz by the broadcasting-satellite service in limited to domestic and regional systems for community reception of educational television programming and public service information. Such use is subject to agreement among administrations concerned and those having services operating in accordance with the table, which may be affected. Unless such agreement includes the use of higher values, the power flux density at the earth's surface produced by emissions from a space station in this service shall not exceed those values set forth in Part 73 of the rules for this frequency band.

NG102 The frequency bands 2500–2655 MHz (space-to-earth) and 2655–2690 MHz (earth-to-space) are allocated for use in the fixed-satellite service as follows:

(a) For common carrier use in Alaska, for intra-Alaska service only, and in the mid and western Pacific areas including American Samoa, the Trust Territory of the Pacific Islands, Guam and Hawaii;

(b) For educational use in the contiguous United States, Alaska and the mid and western Pacific areas including American Samoa, the Trust Territory of the Pacific Islands, Guam and Hawaii.

Such use is subject to agreement with administrations having services operating in accordance with the table, which may be affected. In the band 2500–2655 MHz, unless such agreement includes the use of higher values, the power flux density at the earth's surface produced by emissions from a space station in this service shall not exceed the values set forth in Part 25 of the Rules for this frequency band.

NG104 The use of the bands 10.7–11.7 and 12.75–13.25 GHz in the fixed-satellite service is limited to international systems, i.e., other than domestic systems.

NG111 The band 157.4375–157.4625 MHz may be used for one way paging operations in the special emergency radio service.

NG112 The frequencies 25.04, 25.08, 150.980, 154.585, 158.445, 159.480, 454.000 and 459.000 MHz may be authorized to stations in the petroleum radio service for use primarily in oil spill containment and cleanup operations and secondarily in regular land mobile communication.

NG114 In the Gulf of Mexico offshore from the Louisiana-Texas coast, the frequency band 476–494 MHz (TV channels 15, 16 and 17) is allocated to the Domestic Public and Private Land Mobile Radio Services in accordance with the regulations set forth in parts 22 and 90 respectively.

NG115 In the 174 to 216 MHz band wireless microphones may be authorized to operate on a secondary, non-interfering basis, subject to terms and conditions set forth in 74 of these Rules and Regulations.

NG117 The frequency 156.050 and 156.175 MHz may be assigned to stations in the maritime mobile service for commercial and port operations in the New Orleans Vessel Traffic Service (VTS) area and the frequency 156.250 MHz may be assigned to stations in the maritime mobile service for port operating in the New Orleans and Houston VTS areas.

NG118 Television translator relay stations may be authorized to use frequencies in this band on a secondary basis to stations operating in accordance with the Table of Frequency Allocations.

NG120 Frequencies in the 928–960 MHz band may be assigned for multiple address systems and mobile operations on a primary basis as specified in part 94 of this chapter.

NG124 In the public safety radio service allocations within the bands 30–50 MHz, 150–174 MHz and 450–470 MHz, police radio service licenses are authorized to operate low powered radio transmitters on a secondary, noninterference basis in accordance with the provisions of Sections 2.803 and 90.19(f)(5) of the Rules.

NG127 In Hawaii, the frequency band 488–494 MHz is allocated exclusively to the fixed service for use by common carrier control and repeater stations for point-to-point inter-island communications only.

NG128 In the 535–1705 kHz band, AM broadcast licensees or permittees may use their AM carrier on a secondary basis to transmit signals intended for both broadcast and non-broadcast purposes. In the 88–108 MHz band, FM broadcast licensees or permittees are permitted to use subcarriers on a secondary basis to transmit signals intended for both broadcast and non-broadcast purposes. In the 54–72, 76–88, 174–216 and 740–890 MHz bands, TV broadcast licensees or permittees are permitted to use subcarriers on a secondary basis for both broadcast and non-broadcast purposes.

NG129 In Alaska, the bands 76–88 MHz and 88–100 MHz are also allocated to the Fixed service on a secondary basis. Broadcast stations operating in these bands shall not cause interference to non-Government fixed operations authorized prior to January 1, 1982.

NG133 Stations authorized in the band 73–74.6 MHz as of December 1, 1961 may continue to operate until December 31, 1985. Such stations shall not be required to afford protection to radio astronomy observations within the United States and possessions, however, such stations must afford protection to the observatories of other countries.

NG134 In the band 10.45–10.5 GHz non-Government stations in the radiolocation service shall not cause harmful interference to the amateur and amateur-satellite services.

NG135 In the 420–430 MHz band the amateur service is not allocated north of line A (def. §2.1).

NG139 Pending adopting of further specific rules concerning usage of the band 12.2–12.7 GHz by the fixed and broadcasting-satellite services, systems in these services may be authorized subject to the condition that adjustments in certain systems design or technical parameters may become necessary during the systems lifetime. The necessity for such adjustments, and their extent, will be dependent upon the Final Acts of the 1983 Regional Administrative Radio Conference and subsequent Commission decisions.

NG140 Pending adopting of further specific rules concerning usage of the band 17.3–17.8 GHz by the fixed-satellite service for the purpose of providing feeder links to the broadcasting-satellite service, systems may be authorized for this purpose subject to the condition that adjustments in certain systems design or technical parameters may become necessary during the system lifetime. The necessity for such adjustments, and their extent, will be dependent upon the Final Acts of the 1983 Regional Administrative Radio Conference and subsequent Commission decisions.

NG141 The frequencies 42.40 MHz and 44.10 MHz are authorized on a primary basis in the State of Alaska for meteor burst communications by fixed stations in the Rural Radio Service operating under the provisions of part 22 of this chapter. The frequencies 44.20 MHz and 45.90 MHz are authorized on a primary basis in Alaska for meteor burst communications by fixed private radio stations operating under the provisions of part 90 of the chapter. The private radio station frequencies may be used by Common Carrier stations on a secondary, noninterference basis and the Common Carrier frequencies may be used by private radio stations for meteor burst communications on a secondary, noninterference basis. Users shall cooperate to the extent practical to minimize potential interference. Stations utilizing meteor burst communications shall not cause harmful interference to stations of other radio services operating in accordance with the Table of Frequency Allocations.

NG142 TV broadcast stations authorized to operate in the bands 54–72, 76–88, 174–216, 470–512, and 512–806 MHz may use a portion of the television vertical blanking interval for the transmission of telecommunications signals, on the condition that harmful intereference will not be caused to the reception of primary services, and that such telecommunications services must accept any interference caused by primary services operating in these bands.

NG143 In the band 11.7–12.2 GHz protection from harmful interference shall be afforded to transmissions from space stations not in conformance with international footnote 839 only if the operations of such space stations impose no unacceptable constraint on operations or orbit locations of space stations in conformance with 839.

NG144 Stations authorized as of September 9, 1983 to use frequencies in the band 17.7–19.7 GHz may, upon proper application, continue to be authorized for such operation.

NG145 In the band 11.7–12.2 GHz, transponders on space stations in the fixed-satellite service may be used additionally for transmissions in the broadcasting-satellite service, provided that such transmissions do not have a maximum e.i.r.p. greater than [illegible] dBW per television channel and do not cause greater interference or require more protection from interference than the coordinated fixed-satellite service frequency assignments. With respect to the space services this band shall be used principally for the fixed-satellite service.

NG147 Stations in the broadcast auxiliary service and private radio services licensed as of July 25, 1985, or on a subsequent date following as a result of submitting an application for license on or before July 25, 1985 may continue to operate on a primary basis with the radiodetermination satellite service.

NG148 The frequencies 154.585 MHz, 159.4[illegible] MHz, 160.725 MHz, 160.785 MHz, 454.000 MHz and 459.000 MHz may be authorized to maritime mobile stations for offshore radio location and associated telecommand operations.

NG149 The frequency bands 54–72 MHz, 76–88 MHz, 174–216 MHz, 470–512 MHz, 512–608 MHz, and 614–806 MHZ are also allocated to the Fixed Service to permit subscription television operations in accordance with Part 73 of the rules.

NG151 In the frequency bands 824–849 MHz and 869–894 MHz, cellular land mobile licensees are permitted to offer auxiliary services on a secondary basis subject to the provisions of part 22.

NG152 The band 219–220 MHz is also allocated to the amateur service on a secondary basis for stations participating, as forwarding stations, in point-to-point fixed digital message forwarding systems, including intercity packet backbone networks.

NG153 The 2110–2150 MHz and 2160–2200 MHz bands are reserved for future emerging technologies on a co-primary basis with the fixed and mobile services. Allocations to specific services will be made in future proceedings.

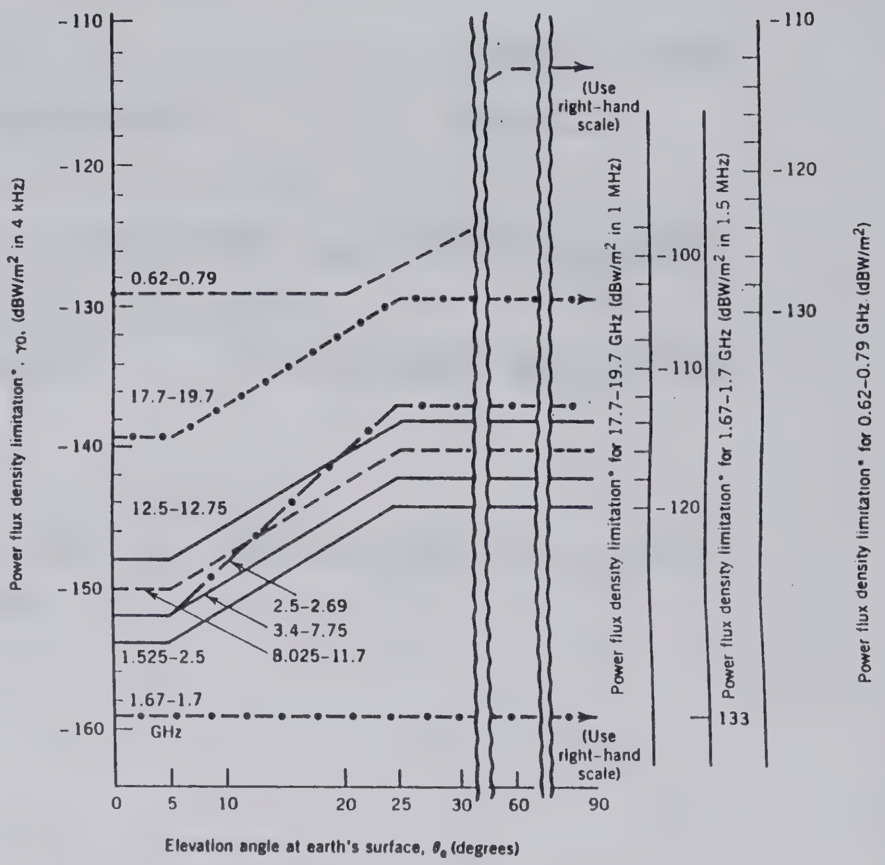
NG154 The 157.1875–157.45 MHz and 161.775–162.0125 MHz bands are also allocated to the land mobile service for assignment to stations as described in part 90 of this chapter.

GOVERNMENT (G) FOOTNOTES

(These footnotes, each consisting of the letter "G" followed by one or more digits, denote stipulations applicable only to the Government.)

Article 28
Power-Flux-Density Limits

- Limitations based on non-interference to terrestrial communication with shared frequency bands
- Promotes sharing of frequency bands by NGSO and GSO systems



*"Limits may exceed on the territory of another country, the administration of which has so agreed." Note: all measurements performed on earth's surface. See the ITU's, *Radio Regulations*, Sections 2552 to 2585 for further details.

FIGURE 3.36 Power flux density limits vs elevation angle for space-to-earth links.

PFD Calculations

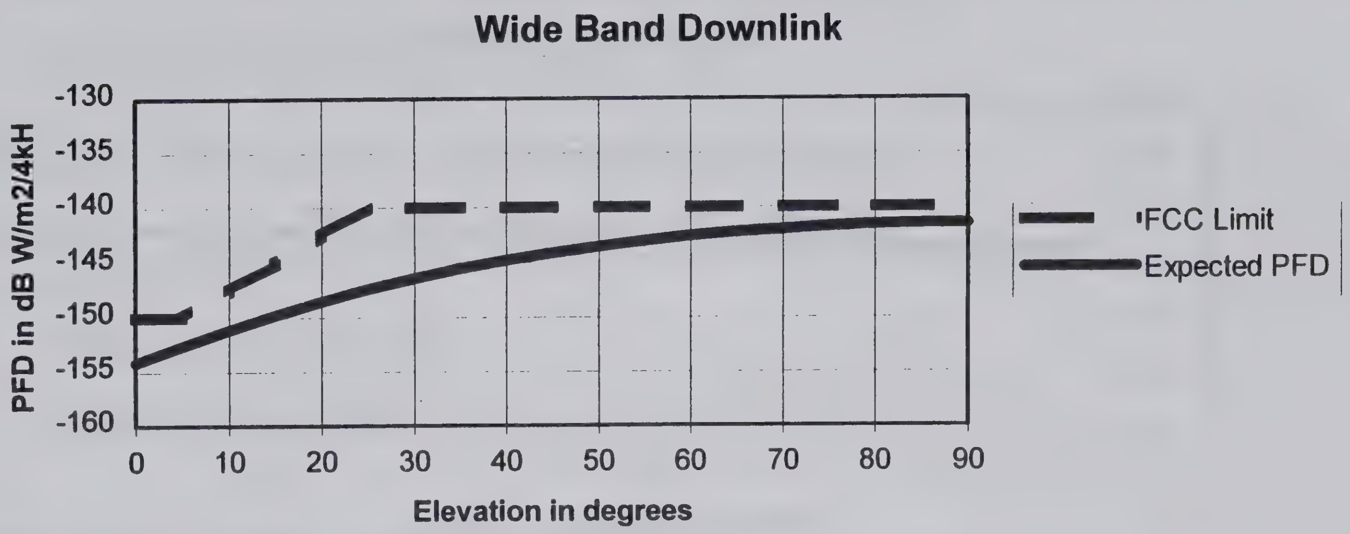
$$\mathrm{PFD} = \frac{\mathrm{EIRP}}{4\pi R^2}$$

$$\mathrm{PFD}_{\mathrm{dB}} = \mathrm{EIRP}_{\mathrm{dB}} - 20*\log(R) - 71 \qquad \text{(R in km)}$$

$$\mathrm{PFD}_{\mathrm{dB}}\,(4\ \mathrm{kHz}) = \mathrm{PFD}_{\mathrm{dB}} + 10\log \frac{4\ \mathrm{kHz}}{\mathrm{BW}}$$

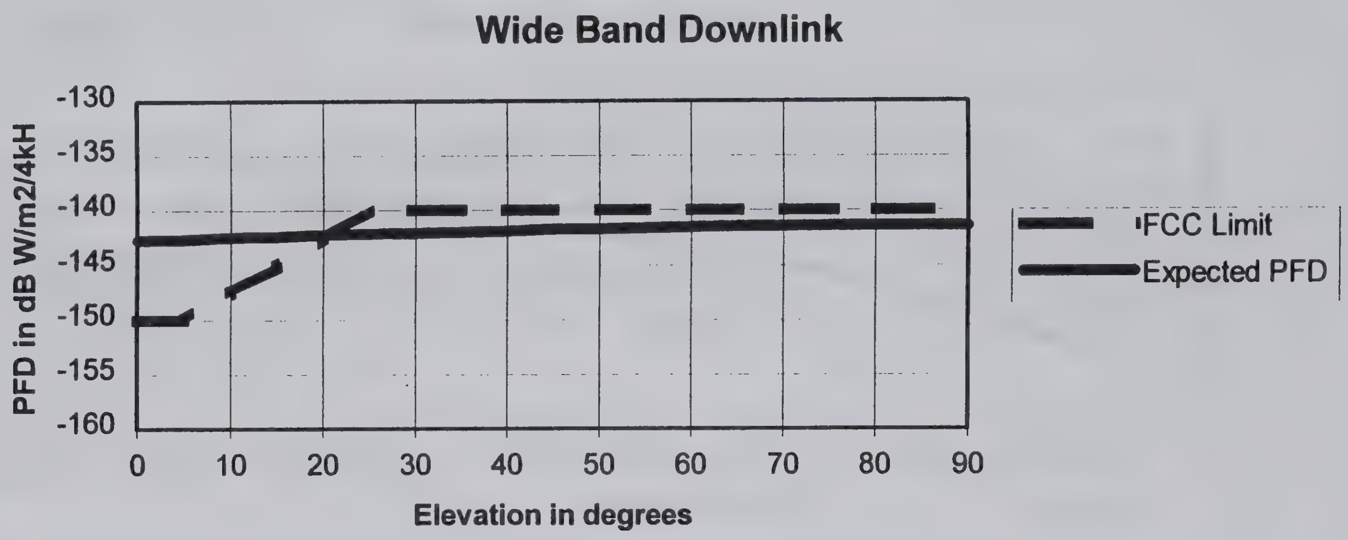
$$\mathrm{PFD}_{\mathrm{dB}}\,(4\ \mathrm{kHz}) = \mathrm{EIRP}_{\mathrm{dB}} - 71 - 20\log(R) + 10\log \frac{4\ \mathrm{kHz}}{\mathrm{BW}}$$

PFD for LEO



750 km orbit
38 dB W EIRP

PFD for GEO



50 dBW EIRP

Appendix 29
Adjacent Satellite Interference

Minimize interference into adjacent satellite at GEO orbits

- **2 ° orbit slot spacing in U.S.**

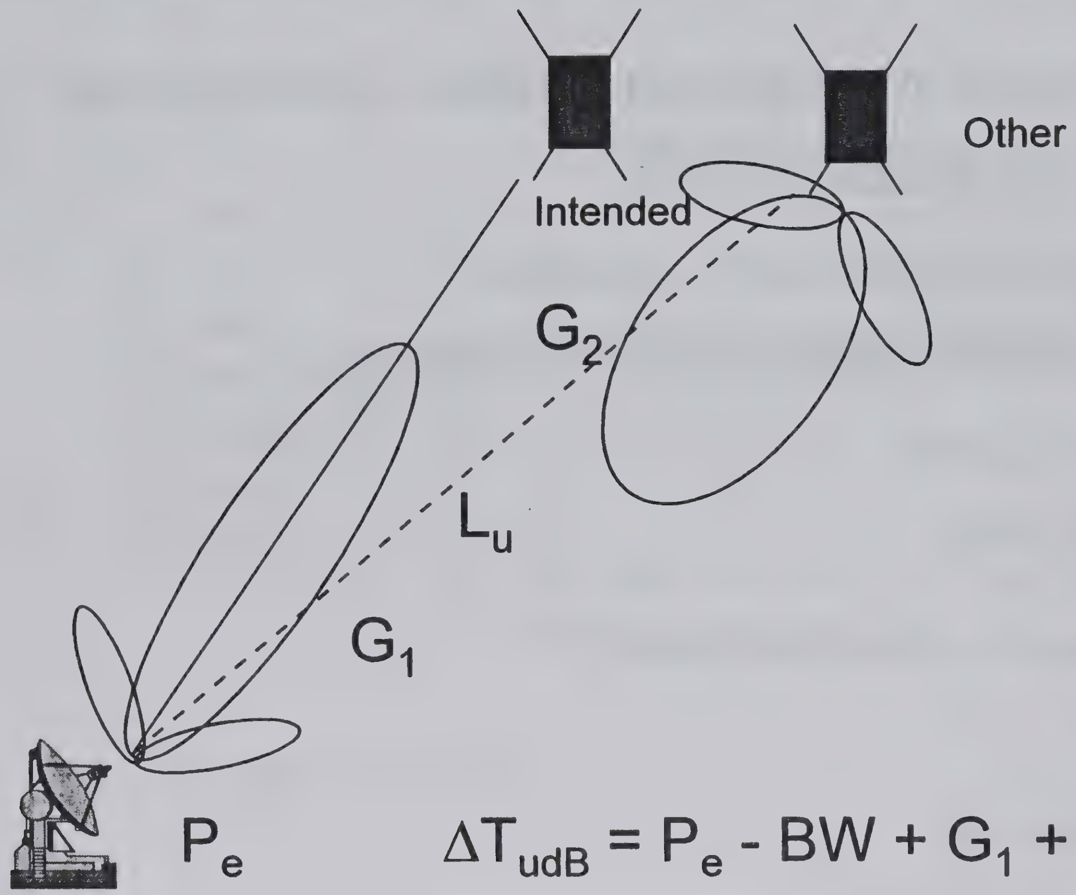
Antenna performance standards specified

- **FCC standard is tighter than ITU standard**
- **FCC part 25.209**
- **ITU-R Rec 465**

Limits on increase to effective noise

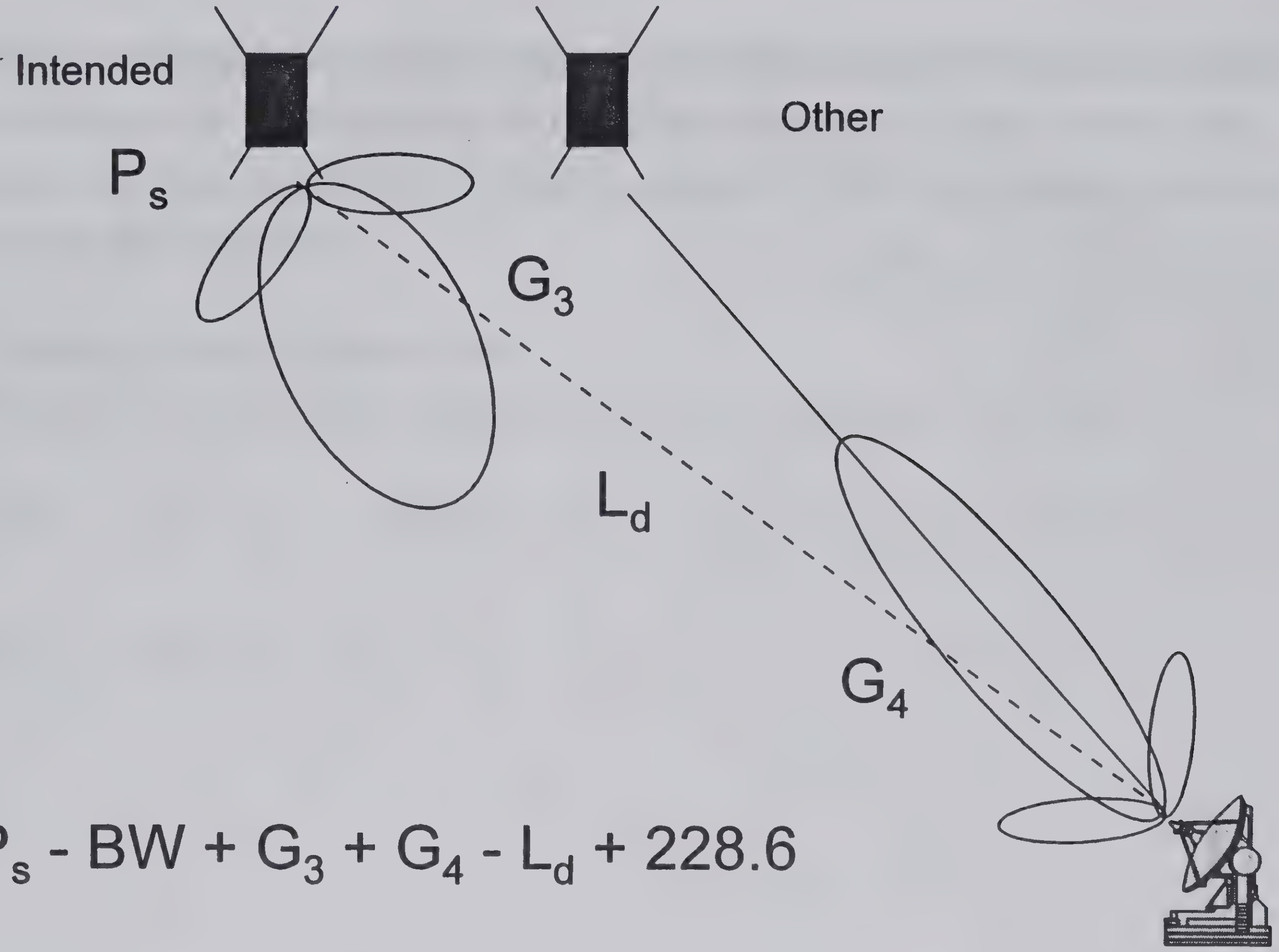
- **6 % $\Delta T/T$**
- **ITU RR app. 29**

Uplink Interference



$$\Delta T_{udB} = P_e - BW + G_1 + G_2 - L_u + 228.6$$

Downlink Interference



$$\Delta T_{ddB} = P_s - BW + G_3 + G_4 - L_d + 228.6$$

Noise Temperature

< 6 % noise temperature increase allowed for non-interference

$$\frac{\Delta T}{T} \leq 6\%$$

$$\Delta T = \gamma \bullet \Delta T_u + \Delta T_d$$

$$T = \gamma \bullet T_u + T_d$$

Link Gain

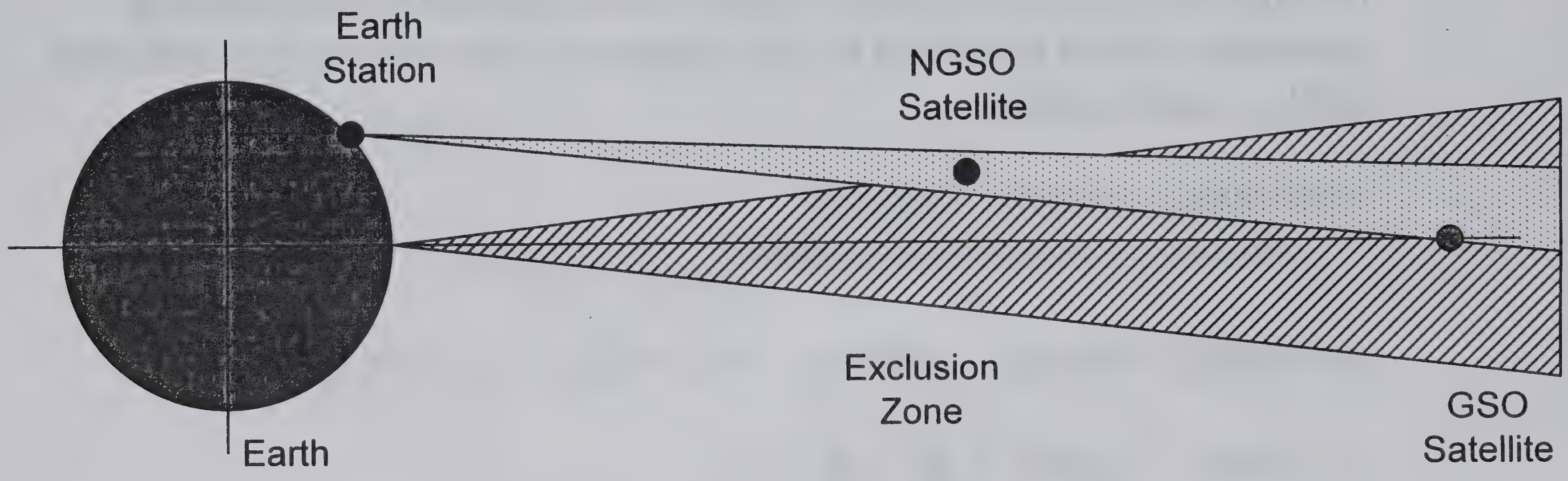
γ **is the transmission gain of a specific satellite link subject to interference evaluated from the output of the receiving antenna of the satellite to the output of the receiving antenna of the earth station**

$$\gamma = \frac{\text{Power at earth receiver}}{\text{Power at satellite receiver}}$$

$$\gamma = EIRP_s - PI + G_e - (EIRP_e - PL + G_s)$$

$$\gamma = EIRP_s - EIRP_e + G_e - G_s$$

NGSO & GSO Sharing



EPFD & APFD

$$epfd = 10 \cdot \log_{10}\left[\sum_{i=1}^{N} 10^{pfd_i/10} \cdot \frac{G_r(\theta_i)}{G_{\max}}\right]$$

where:

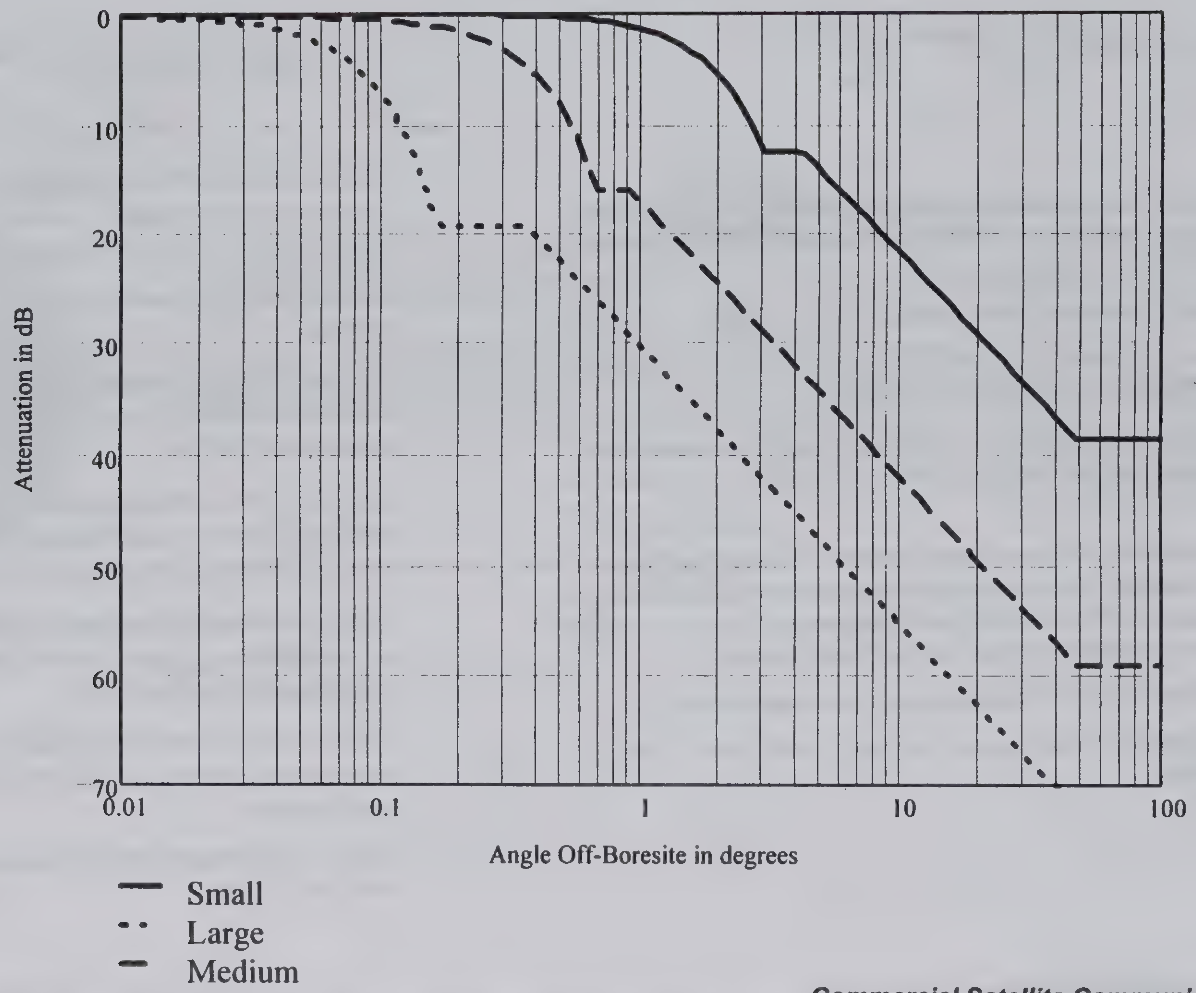
- N is the number of non-geostationary space stations visible from the point considered at the Earth's Surface, within an elevation angle greater or equal to 0°;
- i is the index of the considered non-geostationary space station;
- pfd_i is the power flux-density produced at the point considered at the Earth's surface in dB(W/m^2/4 kHz) or dB(W/ m^2/1 MHz);
- θ_i is the angle between the direction considered towards the geostationary orbit and the direction of the interfering space station in the non-geostationary system;
- $G_r(\theta_i)$ is the gain of the receive reference antenna to be considered as part of a geostationary network. The reference antennas considered are in conformity with Recommendation ITU-R 465-5, with a diameter of 30 cm, 60 cm, 2 m, 3 m, 5 m and 10 m, depending on the frequency band considered.
- G_{max} is the maximum gain of the above receive reference antenna;
- $epfd$ is the computed equivalent power flux-density in dB(W/m^2/4 kHz) or dB(W/m^2/1 MHz).

$$apfd = 10 \cdot \log_{10}\left[\sum_{i=1}^{N} 10^{P_i(t)/10} \cdot \frac{G_t(\theta_i)}{4 \cdot \pi \cdot d_i^2}\right]$$

where:

- N is the number of Earth stations in the non-geostationary system with an elevation angle greater or equal to 0°, from which the point considered in the geostationary orbit is visible.
- i is the index of the earth station considered in the non-geostationary system;
- P_i is the RF power at the input of the transmitting antenna of the Earth station considered in the non-geostationary system in dB(W/m^2/4 kHz) or dB(W/m^2/1 MHz);
- $\theta_i(t)$ is the off-axis angle between the boresight of the Earth station considered in the non-geostationary system and the direction of the point considered in the geostationary-satellite orbit;
- $G_t(\theta_i)$ is the transmit antenna gain of the Earth station considered in the non-geostationary system in the direction of the point considered in the geostationary-satellite orbit;
- d is the distance between the Earth station considered in the non-geostationary system and the point considered in the geostationary-satellite orbit;
- $apfd$ is the aggregate power flux-density in dB(W/m^2/4 kHz) or dB(W/m^2/1 MHz).

Reference Antenna Patterns



Proposed EPFD Limits

TABLE S21-5

Frequency band	Equivalent pfd dB(W/m^2)	Percentage of time during which pfd level may not be exceeded	Reference bandwidth (kHz)	Reference antenna diameter, and reference radiation pattern
10.7 - 10.95 GHz	-179	99.7%	4	60 cm, ITU-R Rec 465-5
	-192	99.9%	4	3m, ITU-R Rec 465-5
	-185	99.97%	4	10 m, ITU-R Rec 465-5
	-170	100%	4	60 cm, 3 m and 10 m, ITU-R Rec 465-5
10.95 - 11.2 GHz	-179	99.7%	4	60 cm, ITU-R Rec 465-5
	-192	99.9%	4	3m, ITU-R Rec 465-5
	-185	99.97%	4	10 m, ITU-R Rec 465-5
	-170	100%	4	60 cm, 3 m and 10 m, ITU-R Rec 465-5
11.2 - 11.45 GHz	-179	99.7%	4	60 cm, ITU-R Rec 465-5
	-192	99.9%	4	3m, ITU-R Rec 465-5
	-185	99.97%	4	10 m, ITU-R Rec 465-5
	-170	100%	4	60 cm, 3 m and 10 m, ITU-R Rec 465-5
11.45 - 11.7 GHz	-179	99.7%	4	60 cm, ITU-R Rec 465-5
	-192	99.9%	4	3m, ITU-R Rec 465-5
	-185	99.97%	4	10 m, ITU-R Rec 465-5
	-170	100%	4	60 cm, 3 m and 10 m, ITU-R Rec 465-5
11.7 - 12.2 GHz in Region 2	-179	99.7%	4	60 cm, ITU-R Rec 465-5
	-192	99.9%	4	3m, ITU-R Rec 465-5
	-185	99.97%	4	10 m, ITU-R Rec 465-5
	-170	100%	4	60 cm, 3 m and 10 m, ITU-R Rec 465-5

Appendix 30
Planned BSS Band

Purpose: To plan Allocation of Ku-Broadcast band

Initiated: 1977

Frequencies:

Region 1	11.7 - 12.5 GHz
Region 2	12.2 - 12.7 GHz
Region 3	11.7 - 12.2 GHz

Plan:

1 Beam ID (country or region)
2 Nominal orbital position
3 Channel Number
4 Boresight geographical coordinates
5 Antenna beamwidth (major and minor axis)
6 Orientation of ellipse
7 Polarization
8 EIRP
9 Remarks

Plan
Sample Table

12224,00 MHz (1)

1	2	3	4		5		6	7	8	9	
ALS00002	−166.20	1	−149 66	58.37	3.76	1.24	170	1	59.7	9/GR1	10
ALS00003	−175.20	1	−150.98	58.53	3.77	1.11	167	1	60.0	9/GR2	10
ARGINSU4	−94.20	1	−52.98	−59.81	3.40	0.80	19	1	59.9	9/GR3	
ARGSUR04	−94.20	1	−65.04	−43.33	3.32	1.50	40	1	60.7	9/GR3	10
B CE311	−64.20	1	−40.60	−6.07	3.04	2.06	174	1	61.6	8 9/GR7	10
B CE312	−45.20	1	−40.27	−6.06	3.44	2.09	174	1	61.0	8 9/GR9	10
B CE411	−64.20	1	−50.97	−15.27	3.86	1.38	49	1	62.6	8 9/GR7	10
B CE412	−45.20	1	−50.71	−15.30	3.57	1.56	52	1	62.7	8 9/GR9	10
B CE511	−64.20	1	−53.10	−2.90	2.44	2.13	104	1	63.0	8 9/GR7	10
B NO611	−74.20	1	−59.60	−11.62	2.85	1.69	165	2	62.8	8 9/GR8	10
B NO711	−74.20	1	−60.70	−1.78	3.54	1.78	126	2	62.8	8 9/GR8	10
B NO811	−74.20	1	−68.76	−4.71	2.37	1.65	73	2	62.8	8 9/GR8	
B SU111	−81.20	1	−51.12	−25.63	2.76	1.05	50	1	62.8	8 9/GR6	10
B SU112	−45.20	1	−50.75	−25.62	2.47	1.48	56	1	62.2	8 9/GR9	
B SU211	−81.20	1	−44.51	−16.95	3.22	1.36	60	1	62.5	8 9/GR6	10
B SU212	−45.20	1	−44.00	−16.87	3.20	1.96	58	1	61.3	8 9/GR9	
B AHIFRB1	−87.20	1	−76.06	24.16	1.81	0.80	142	1	61.6		
BERBERMU	−96.20	1	−64.77	32.32	0.80	0.80	90	2	56.8		
B ERBER02	−31.00	1	−64.77	32.32	0.80	0.80	90	1	56.9	2	10
B OLAND01	−115.20	1	−65.04	−16.76	2.49	1.27	76	1	67.9	9/GR5	
CAN01101	−138.20	1	−125.63	57.24	3.45	1.27	157	1	59.5	9/GR10	10
CAN01201	−138.20	1	−112.04	55.95	3.35	0.97	151	1	59.6	9/GR10	10
CAN01202	−72.70	1	−107.70	55.63	2.74	1.12	32	1	59.6		
CAN01203	−129.20	1	−111.48	55.61	3.08	1.15	151	1	59.5	9/GR12	10

Filing Requirements
Satellite System

1	Name and address of applicant
2	Name and address for inquires
3	Type of authorization requested
4	General description of overall system
	facilities
	operations
	services
5	RF plan (beacon, TT&C, Transponders
	frequency
	polarization
	bandwidth
	output power
	EIRP
6	Orbital locations (constellation description)
	# of planes
	# of satellites/plane
	inclination
	eccentricity
	orbital period
	apogee, perigee
	arg of perigee
	RAAN
	active service arcs
7	Predicted antenna gain contours
	Receiver antennas
	Transmit antennas

8	Types of services to be provided
	Link budgets
9	Accuracy of GEO orbit
10	Calculation of Power Flux Density
11	Arrangement for TT&C
12	Physical characteristics of satellite
	weight
	dimensions
	Mass estimates (ground, orbit)
	power (BOL, EOL)
	lifetime
13	Financial qualification of applicant (25.140 b-e)
	estimated costs
	estimates operating expenses
	balance sheet for latest fiscal year
	financing arrangements
14	Statement on common carrier operations
15	Construction and launch schedule
16	Public interest considerations
	Interference analysis
17	Domestic FSS requirements (25.140)
18	RDSS requirements (25.141)
19	MSS L-band (52 FR 4017) (1.5/1.6 GHz)
20	NGSO MSS service requirements (25.142)
21	MSS requirements (25.143) (1.6/2.4 GHz)

Appendix 28
Coordination Contours

- **Defines potential region of interference with earth station**
- **Interference from earth station transmitter into other services in the same band**
- **Interference from other services into satellite receive band**
- **Minimum coordination distance is 100 km**
- **Procedure detailed in FCC part 25 and ITU RR appendix 28**

Coordination Requirements

4- 26

- **Determine coordination distance contours**
- **Provide to each existing licensee with in the contour**
    - **Geographical coordinates of earth station**
    - **Operating frequencies and emissions**
    - **Antenna height above ground**
    - **Ground station elevation above mean sea level**
    - **Antenna gain patterns**
    - **Pointing direction of earth station antenna**
    - **Horizon elevation plot**
    - **Minimum elevation angle**
    - **Maximum EIRP in 4 kHz band**
    - **Maximum RF power in 4 kHz band**
    - **Maximum permissible RF interference**
    - **Plot of coordination distance contours**

Regulations Summary

- **Table of Allocations**
- **Power-Flux-Density Limits**
- **Adjacent Satellite Interference**
- **BSS Planned Bands**
- **Earth Station Coordination**
- **There are other regulations relating to specific areas**
    - **Interference in deep space bands**
    - **Spectral occupancy**

Commercial Satellite Communication Applications
Course No. 9SV109

Module 4
Regulations
(Politics, Politics, Politics, ...)

October 24, 1997

Boeing Information, Space, & Defense Systems

Module Objectives / Assessments

What you can learn in this module:

- **Who the major regulating authorities are for satellite communications**
- **What is the purpose of the regulations**
- **What some of the major areas of regulation are**

How to measure your success:

- **Can you name three regulating agencies involved in satellite communications?**
- **Can you name three particular areas of satellite communications that are regulated**

Regulatory Organizations

ITU - International Telecommunications Union

International frequency coordination and recommendations for standards

FCC - Federal Communications Commission

U.S. regulatory agency for commercial communications

NTIA - National Telecommunication and Information Administration

U.S. regulatory agency for government communications

URL's

4- 3

ITU	International Telecommunications Union	www.itu.ch
FCC	Federal Communications Commision	www.fcc.gov
NTIA	National Telecommunications and Information Administration	www.ntia.doc.gov
EBU	European Broadcast Union	www.ebu.ch
ERO	European Radiocommunication Office	www.ero.dk
ETSI	European Telecommunication Standards Institute	www.etsi.fr
ISO	International Standards Organization	www.iso.ch
IEC	International Elecrotechnical Commision	www.iec.ch
TIA	Telecommunication Industry Association	www.tiaonline.org
EIA	Electronic Industry Association	www.eia.org

List www.rfweb.com/assoc.html

Commercial Satellite Communications Applications

Course No. 9SV109

Module 5

Direct-to-Home Television Services by Satellite

Module Agenda

Time	Topic
10 Min	DTH Overview
30 Min	DTH Services Around the World
40 Min	DTH Services in the U.S.
40 Min	DTH Technology

Module Objectives / Assessments

What you can learn in this module:

- Differences between DTH services and systems around the world
- Fixed satellite service Vs. broadcast satellite service DTH
- Basics of DTH digital satellite technology

How to measure your success:

- What are the fundamental differences between FSS and BSS direct-to-home television services?
- Generally describe MPEG video

Four Types of TV Broadcasting

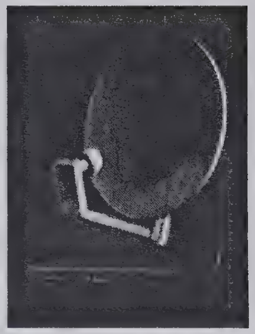
- **Distribution from studio to local broadcast station**
- **Transmission from event location to studio**
- **Distribution from studio to cable headends**
- **Distribution from studio directly to the home (DTH)**

Direct-to-Home Satellite TV Broadcasting

- **Entertainment TV programming**
- **Alternative to cable television, multi-channel microwave distribution service, or cassette rentals**
- **Small, low-cost receive equipment**
- **Monthly subscriptions for program content**

Frequency Bands for DTH In U.S.

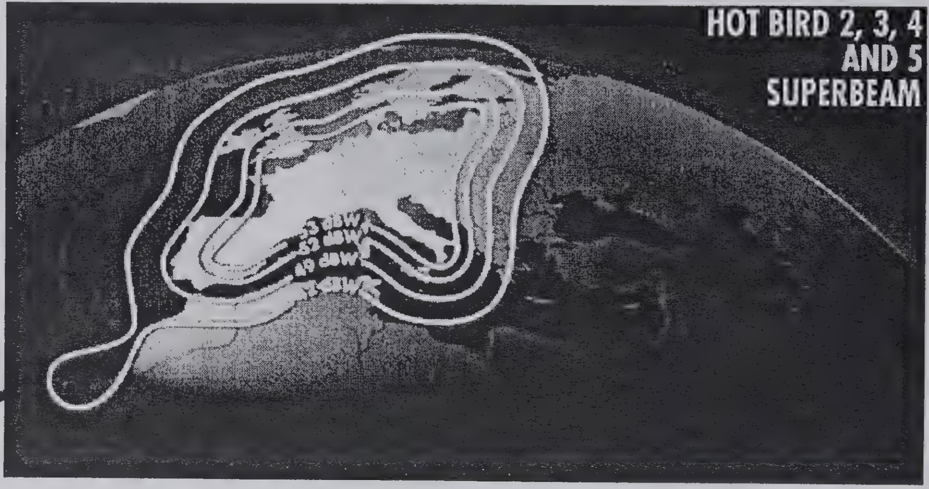
Band	Frequency (GHz)	Antenna Size
C-band	3.7 to 4.2	10’
Ku-band FSS	11.7 to 12.2	24” to 36”
Ku-band BSS	12.2 to 12.7	18”



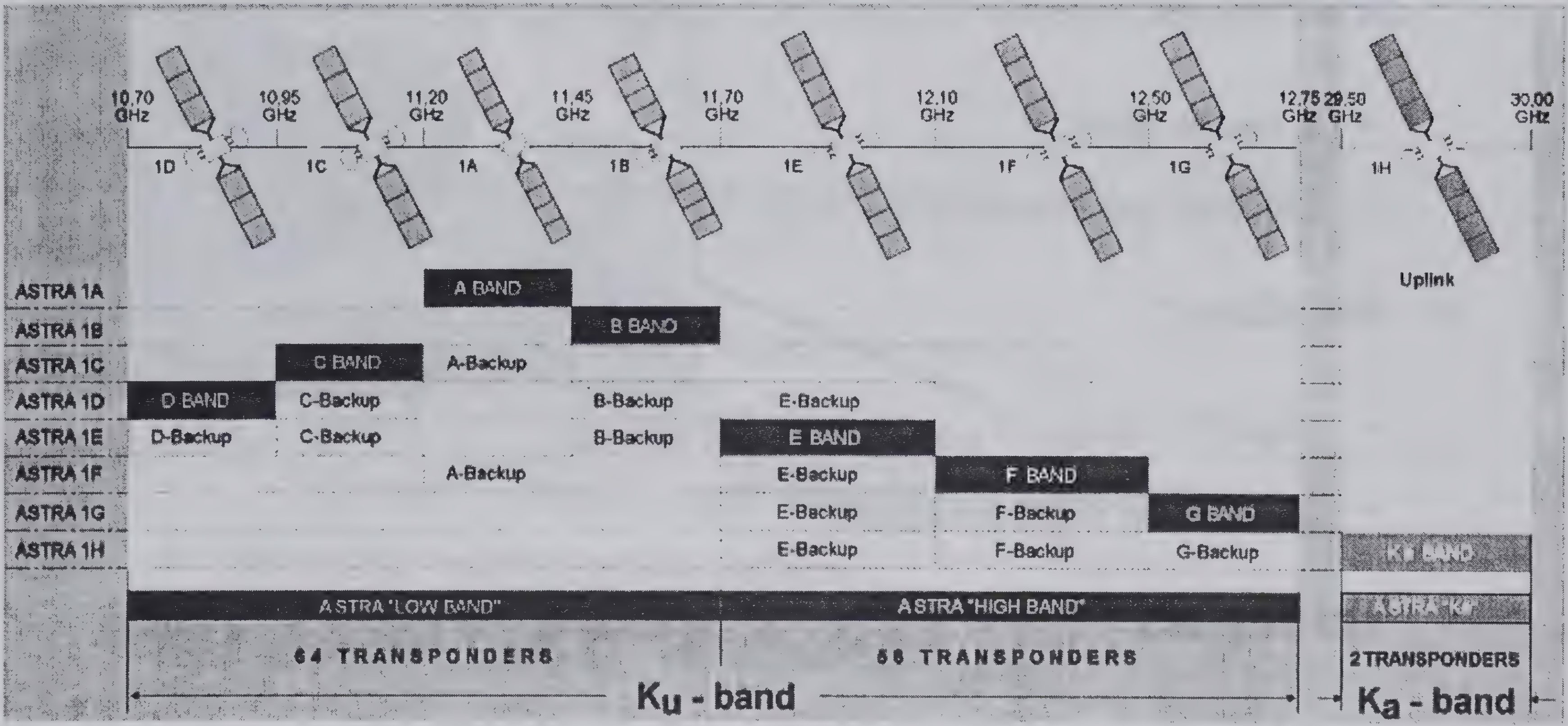
FSS - Fixed Satellite Service BSS - Broadcast Satellite Service

DTH In Europe

- Almost exclusively in Ku-band
- Developed in parallel with cable
- First with high power (French TDF - 230 watts RF)
- BSkyB begins broadcasting analog TV
- SES/ Astra
  - A,B,C,D,E,F,&G satellites
  - 45 to 85 W
  - 52 dBW EIRP
- Eutelsat/Hotbird

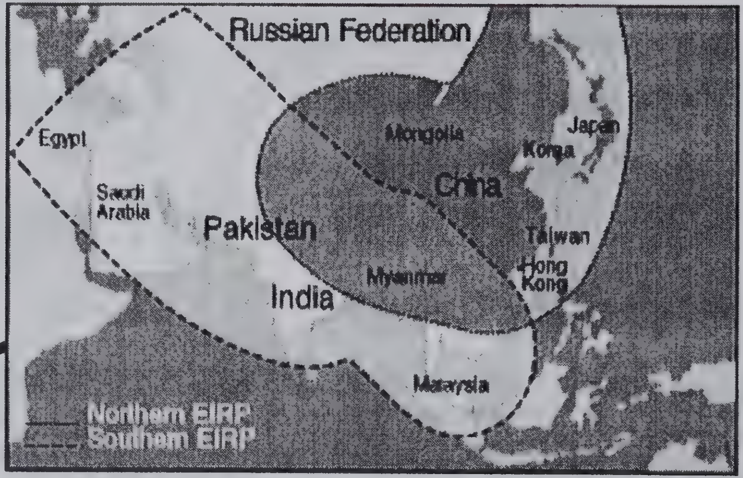


SES/Astra Satellite System



DTH In Asia

- **Aussat A**
  - **1 meter dish**
  - **Medium powered FSS**
- **AsiaSat 1**



  - **Star TV - C-band entertainment service**
  - **24 - 8 watt transponders**
- **Indonesia**
  - **C-band to avoid Ku-band rain attenuation**

DTH In Japan

- NHK delivers DTH via satellites starting in 1980
- BSAT 1A
  - Analog signals in the BSS band
  - NHK
    - – DBS-1 News, sports, & general interest
    - – DBS-2 Cultural content
    - – Hi-Vision - World's only daily HDTV broadcast
  - WOWOW - subscription service
- New digital FSS/DTH services
  - PerfecTV, JSkyB, and DirecTV Japan

DTH In Latin America

Latin America DTH Satellite Details

95° W
Galaxy 3R
11.7 to 12.2 GHz
Dec 95
16 @ 27 MHz
8 @ 54 MHz
63 watts
Circular
HS-601

Galaxy 8I
11.45 to 11.7 GHz
Fall 97
27 MHz
16 @ 240 watts
32 @ 120 watts
Circular
HS-601

58° W
PAS 5
10.7 to 10.95 GHz
11.2 to 11.7 GHz
Aug 97
6 @ 60 watts
18 @110 watts
36 MHz
Linear
HS-601HP
~10KW

43° W
PAS 6
10.7 to 10.95 GHz
11.2 to 11.45 GHz
Aug 97
36 @ 36 MHz
100 watts
Linear
Loral FS-1300

Orbital
Location
Name
Frequency
Operational Date
Bandwidth
Polarization
Spacecraft Bus

AIS

Near Term Global DBS Service Providers

Circular and Linear Polarization

United States/Canada

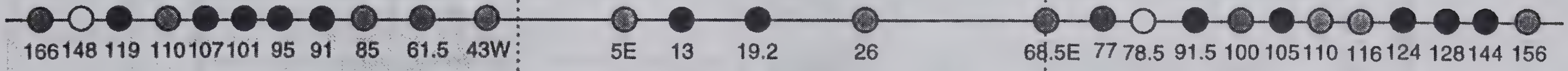
DirecTv	DBS 1, 2, &3	6/94
USSB	DBS 1	6/94
DISH	Echostar I& II	3/96
Tempo	Tempo 2	TBD
Primestar/ Sky	Sky 1 Sky 2	5/98 3/98
DISH+	Echostar III	10/97
Loral	61.5°	TBD
Tempo	Tempo 1(119or166)	3/98
Primestar	GE-2 (FSS)	94
ExpressVu	Anik E2 (FSS)	9/97
ExpressVu	TBD (BSS)	Late 98

Europe

Canal+	Astra	97
DF1	Astra	97
CSD-Spain	Astra	97
Multichoice	Astra	97
Premiere	Astra	97
BSkyB (dig)	Astra	3/98
BSkyB (anlg)	Astra	97
Telepiu	Hotbird 2	97
TPS-France	Hotbird 2	97
Multichoice Hellas	Hotbird 2	97
RAI	Hotbird 2	97
AB Sat	Eutalsat II f1	97
TBD	Sirius 2	10/97

Asia/India/Japan

DirecTV Japan	Superbird C	9/97
PerfecTV	JCSat 3	96
JSkyB	JCSat 3	97
JSkyB	JCSat 6	7/98
NHK/Wowow	BSat 1A	96
ISkyB	PanAmSat 4	97
CCTV	Asiasat 2	97
Korea CATV	Koreasat 1/2	96
TBD	Apstar 2R	10/97
TBD	Asiasat 3	11/97



Latin America

DirecTV Latin Amer.	Galaxy 8I	12/97
Sky	PanAmSat 6	9/97

Middle East & Africa

Arabesque	Hotbird 2	97
1st Net	Arabsat 2A	97
1st Net	PanAmSat 4	97
Showtime Network	PanAmSat 4	97
Multichoice South Africa	PanAmSat 4	97

Indonesia/South Pacific

TBD	Agila 2	9/97
ASTRO	Measat	96
Galaxy	Optus B3	97

☐ AIS Compatible - Circular

⬚ AIS Compatible - Linear

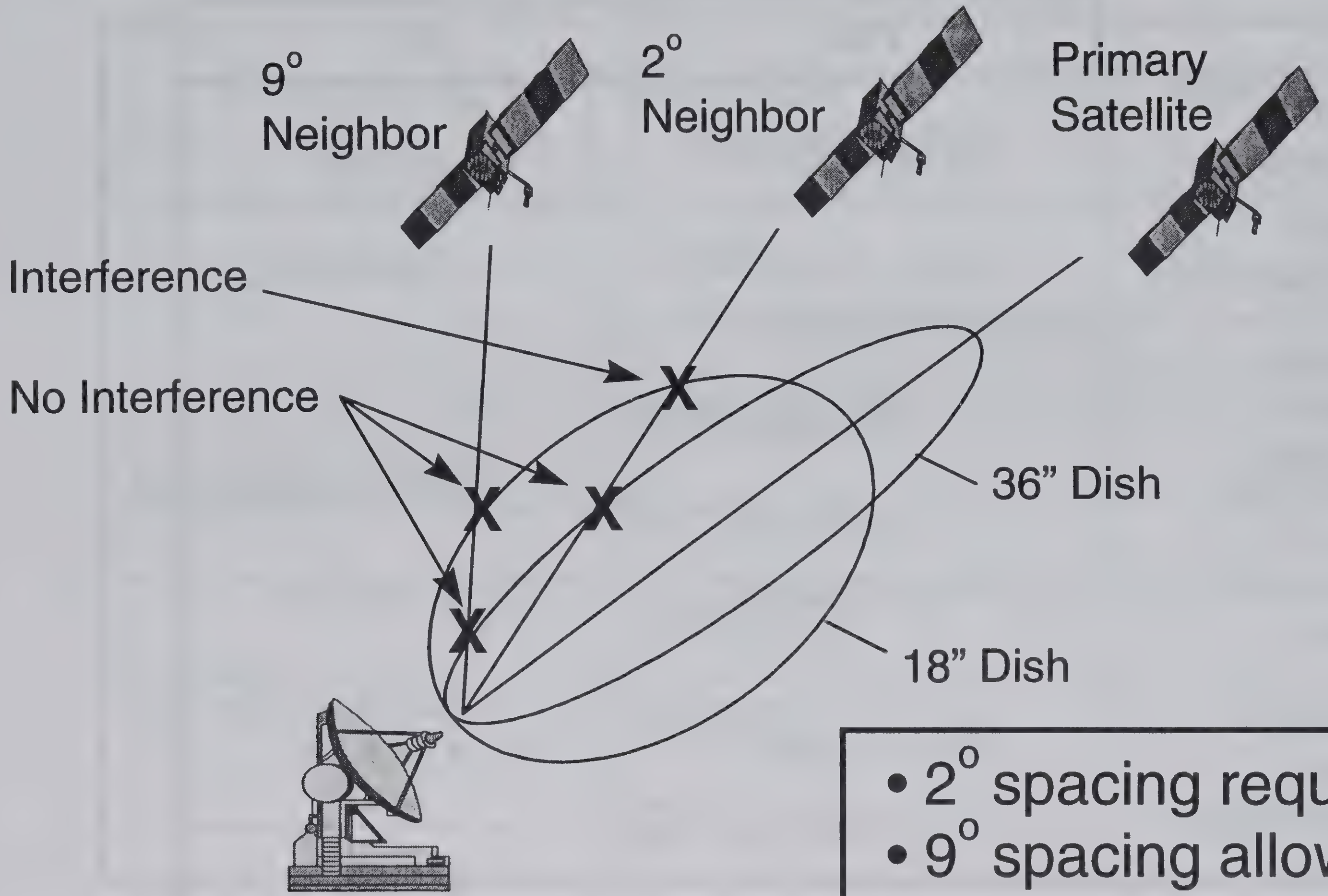
Service Providers for DTH

Frequency Band	Service Providers	Receiver Technology
C-band	Cable Programmers	Videocipher
Ku-band FSS	Primestar Alphastar	DVB
Ku-band BSS	DirecTV USSB Echostar	DSS DVB

Differences Between FSS and BSS

	FSS	BSS
Downlink Frequency	11.7 - 12.2 Ghz	12.2 - 12.7 Ghz
Uplink Frequency	14.0 - 14.5 Ghz	17.3 - 17.8 Ghz
Spacing Between Satellites	2^{o}	9^{o}
Typical Transponder Power	60 to 100 watt	120 to 240 watt
Typical EIRP	46 to 51 dBW	50 to 54 dBW
Polarization	Linear	Circular

Orbital Interference Limitations



- 2° spacing requires 36" dish
- 9° spacing allows 18" dish

DTH in the U.S.

- Satellite Television Corporation
  - Subsidiary of COMSAT
  - Establish market share before full cable penetration
  - Started building new satellite for analog TV delivery
  - Shut down due to lack of programming/ investment capital
- USCI
  - Fixed satellite service of Ku-band
  - Leased transponders
  - 100,000 subscribers
  - Lost out to cable growth and resurgence of C-band DTH

FCC BSS History

- Round One Filings
    - 6 of 14 rejected by FCC
    - 2 filings from prison inmates
    - 1 filing sent to round 2 for being 12 minutes late
    - STC, Dominion, and USSB
- Round Two
    - Hughes Communications Galaxy
- Round Five
    - Echostar
    - Tempo (TCI)
    - Loral
- Round Six
    - MCI ($682M in FCC auction)

16 year process from 1980 to 1996

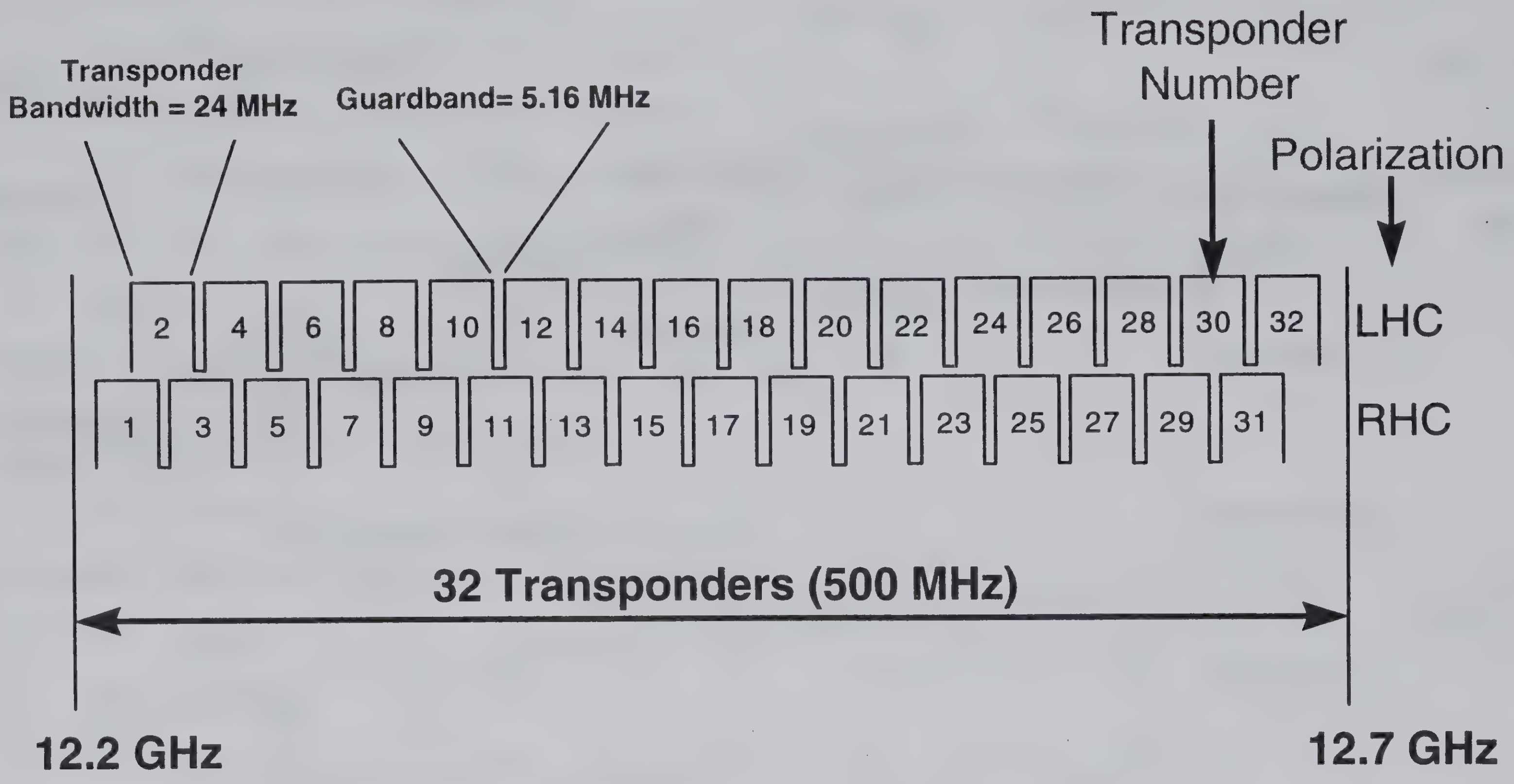
Current Domestic BSS FCC Licensees

Orbital Location
Name
# of Transponders

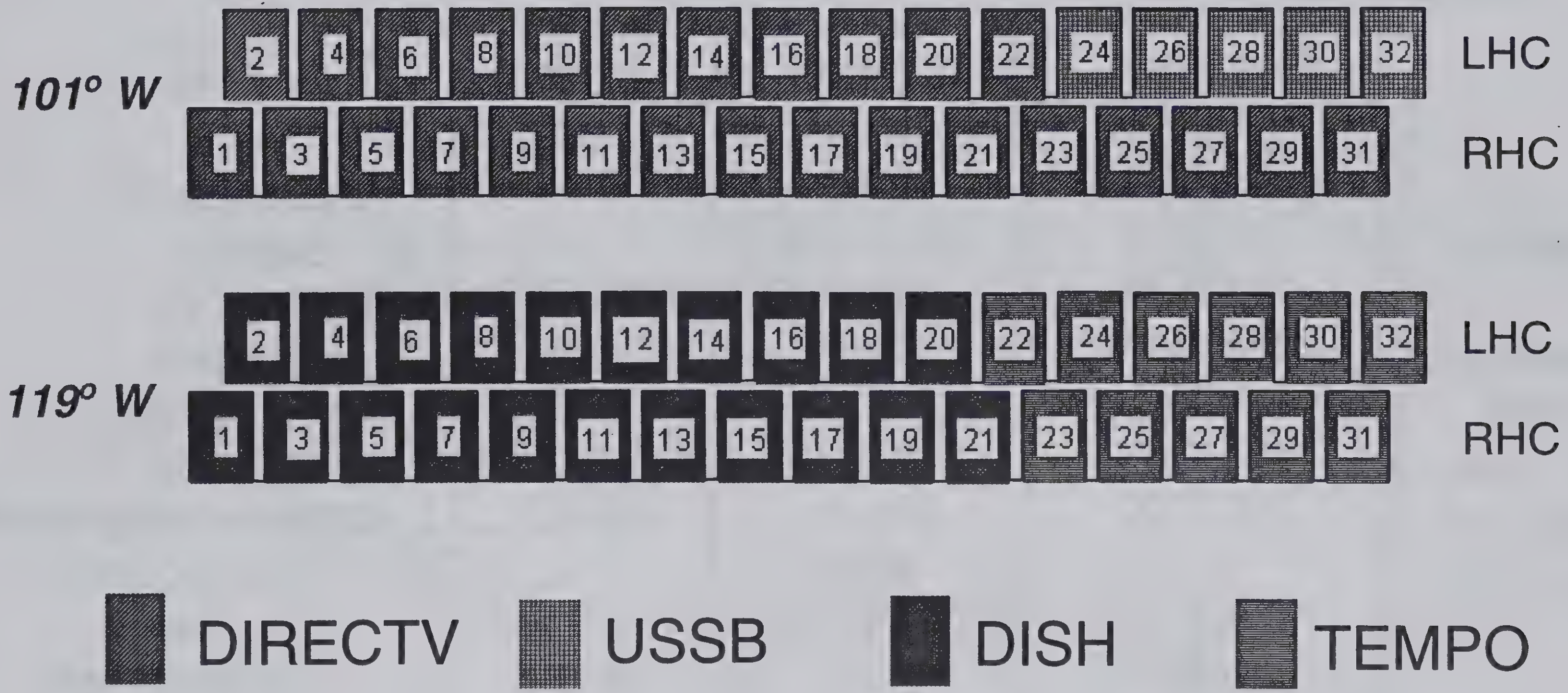
175° W	166° W	157° W	148° W	119° W	110° W	101° W	61.5° W
Echostar **32**	Loral SpaceCom **11**	DIRECTV **27**	Echostar **24**	Echostar **21**	MCI **28**	DIRECTV **27**	Echostar **11**
	Tempo **11**	Unassigned **5**	USSB **8**	Tempo **11**	USSB **3**	USSB **5**	Loral SpaceCom **11**
	Dominion **8**				Echostar **1**		Dominion **8**
	Echostar **1**						Unassigned **2**
	Unassigned **1**						

Full CONUS Coverage

BSS Frequency Plan



BSS Transponder Assignments


101° W
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 LHC
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 RHC
119° W
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 LHC
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 RHC
DIRECTV
USSB
DISH
TEMPO

BSS Satellites

148° W

Echostar-4
2/98
32 120W
switchable
LM AX2100

119° W

118.7° W
Echostar-1
12/95
16R 130W
GE 7000

118.6° W
Echostar-2
9/96
16L 130W
GE 7000

118.8° W
Tempo-2
4/97
32-107W
16-214W
Loral FS-1300

110° W

109.8° W
Sky 1
5/98
16 L/16R
120W
Loral

110.2° W
Sky 2
3/98
32R 120W
Loral

101° W

101.2° W
DBS-1
12/93
16L 120 W
HS-601

100.7° W
DBS-2
8/94
16R 120W
HS-601

100.9° W
DBS-3
6/95
16 120W
HS-601

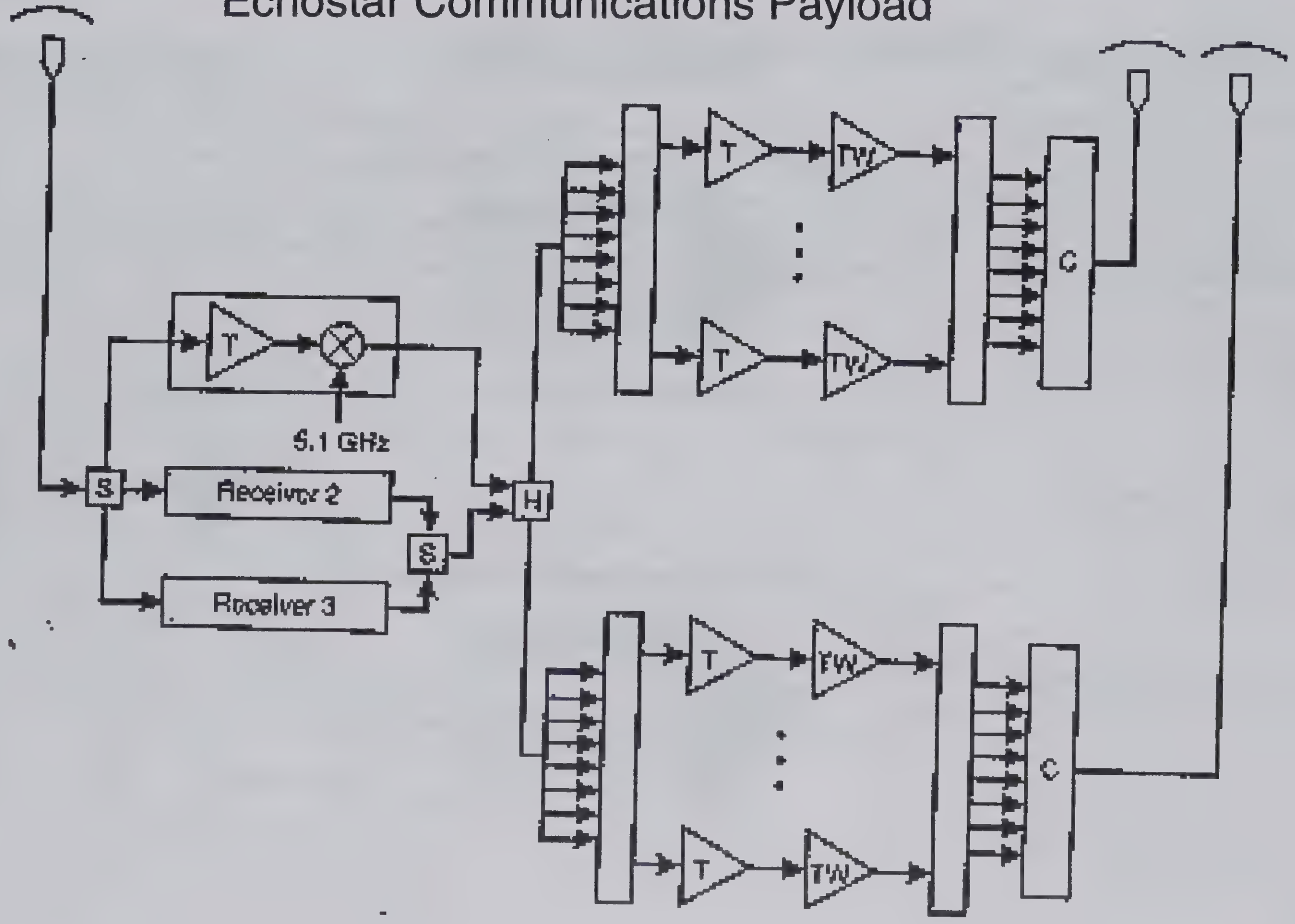
61.5° W

Echostar-3
Sept 97
32 120W
switchable
LM AX2100

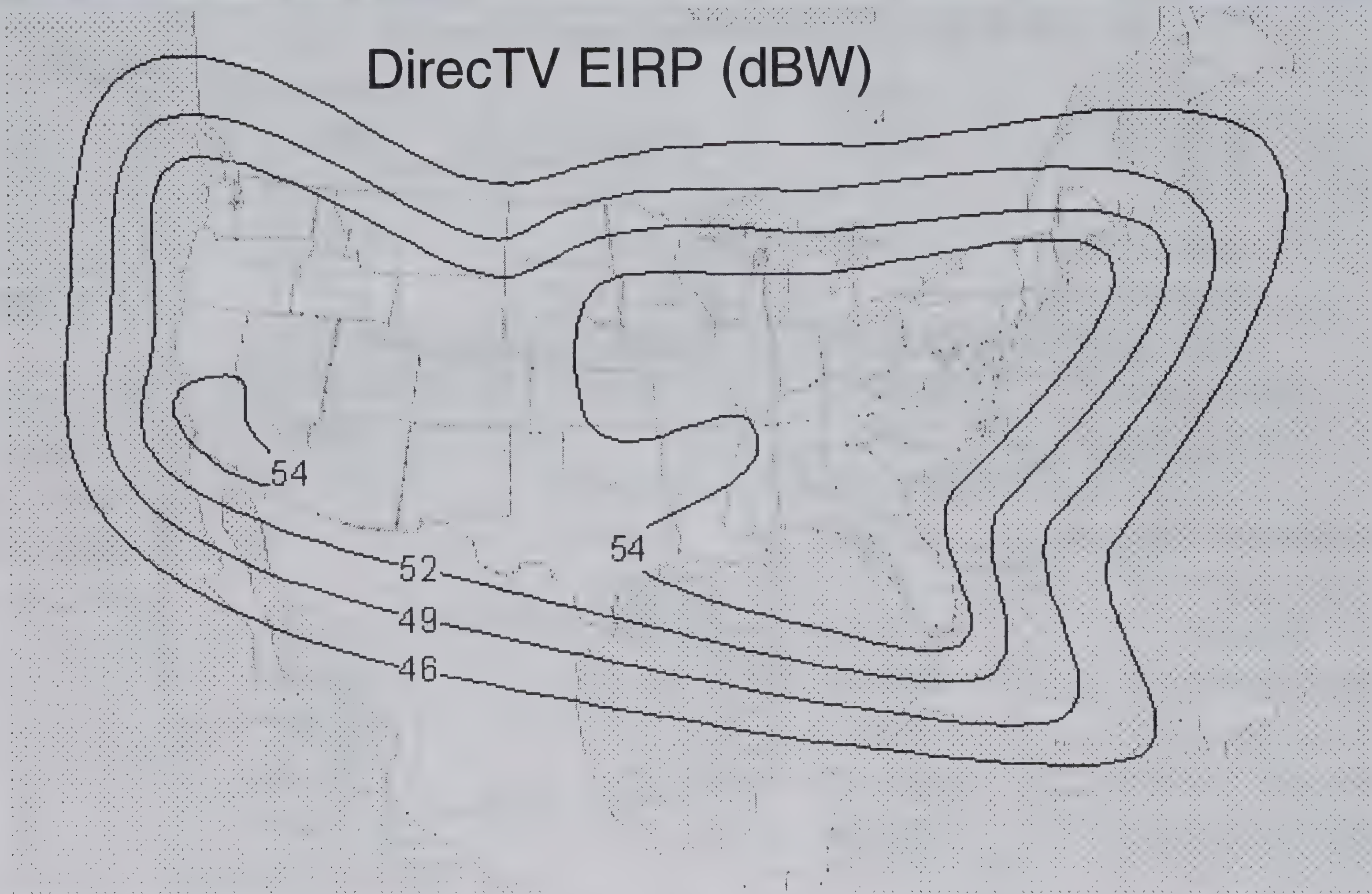
Orbital Assignment
Orbit Location
Name
Launch Date
Transponders
[L = LHCP, R = RHCP]
Spacecraft Bus

DTH Satellite Payload

Echostar Communications Payload

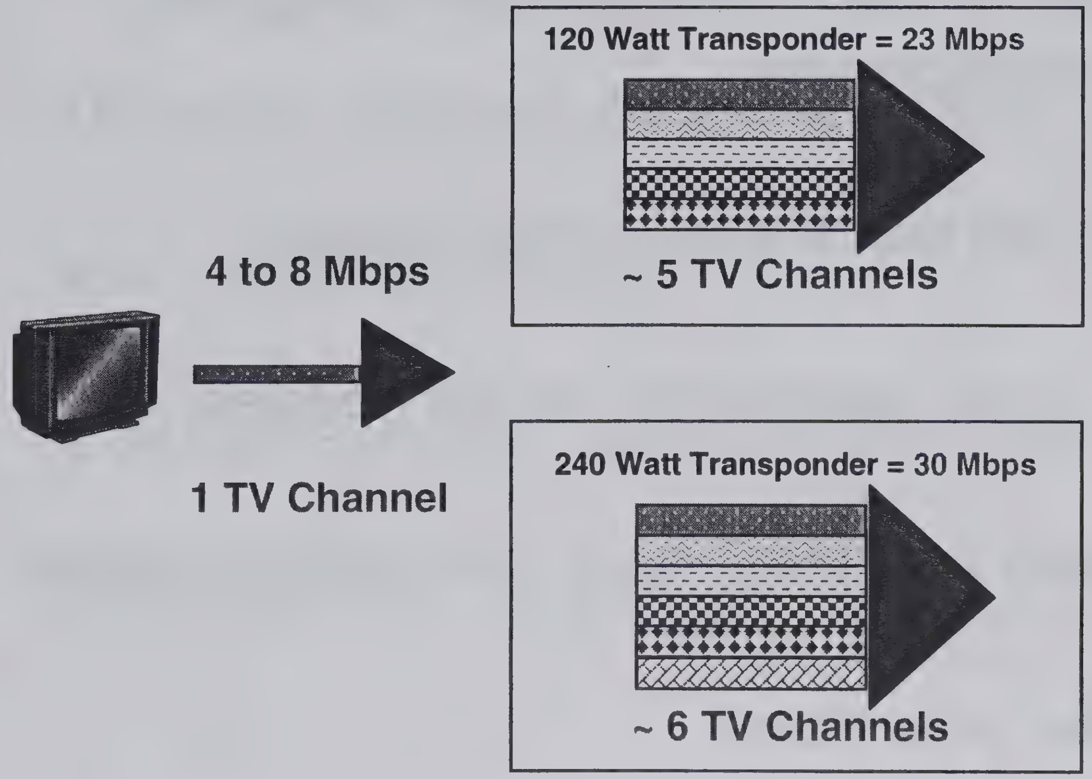


DBS Satellite Power Levels



DirecTV EIRP (dBW)

Number of TV Channels Per Orbit Slot



TV Channel

4 to 8 Mbps

1 TV Channel

Transponder

120 Watt Transponder = 23 Mbps

~ 5 TV Channels

240 Watt Transponder = 30 Mbps

~ 6 TV Channels

Orbit Slot

32 Transponders/Orbit Slot

160 TV Channels

192 TV Channels

Statistical Multiplexing

- Take advantage of varying instantaneous bandwidth needs of each of television program multiplexed in transponder
- Mix sports with old black and white movies
- Each program grabs bandwidth when needed
- Settable minimum and maximum data rate/program
- Programs can be prioritized

Why Compression Is Needed

Example:

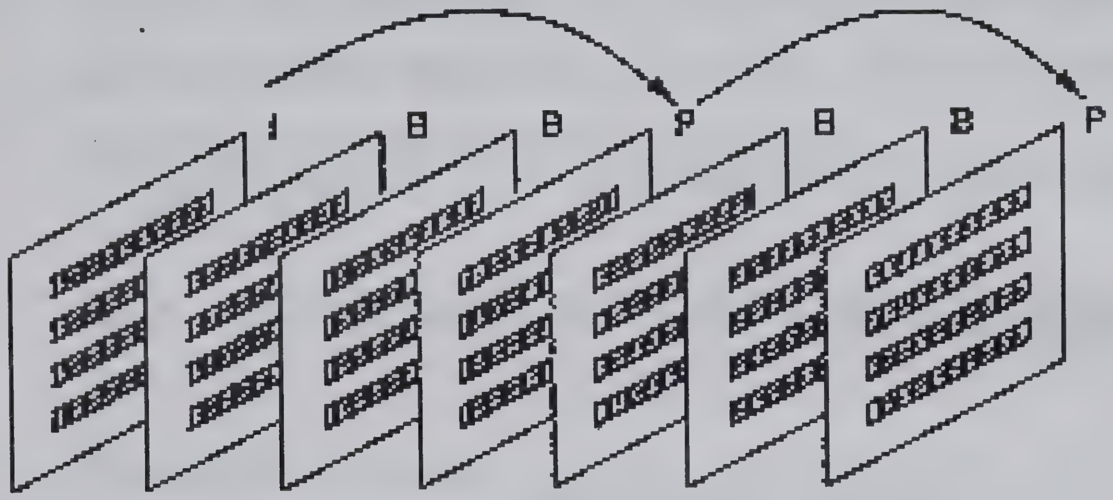
Television picture with 576 lines and 720 pixels/line =

414, 720 pixels/frame

x 30 frames/sec = 12 million pixels/sec

x 64 bits/pixel = **796 Mbps**

MPEG Overview

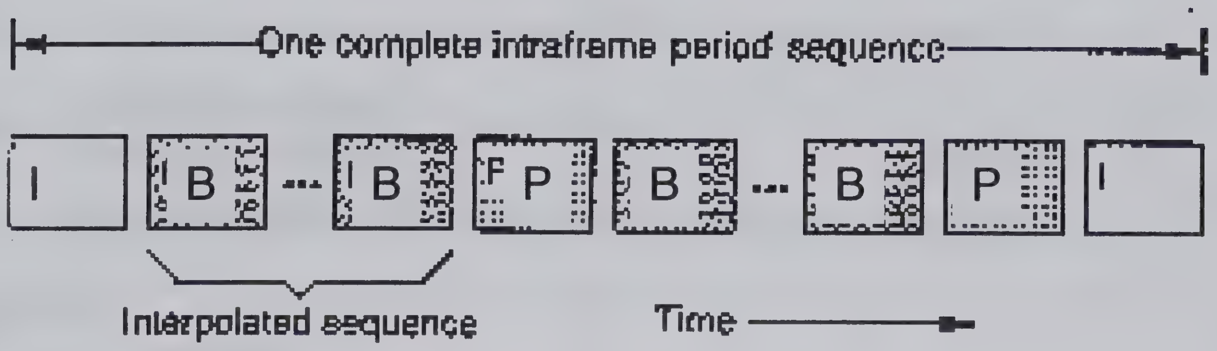


Key:

I	Intraframe picture
P	Predicted picture
B	Interpolated picture

- I pictures encoded individually
- P pictures predicted from nearest P or I frames/ include motion compensation
- B pictures interpolated from I pictures

MPEG Sequence



Key:

I	Intraframe picture
P	Predicted picture
B	Interpolated picture

Global Television Standards

Format	Region
NTSC	North America South America Southeast Asia
PAL	Europe China South America Southeast Asia Africa
SECAM	Europe Africa

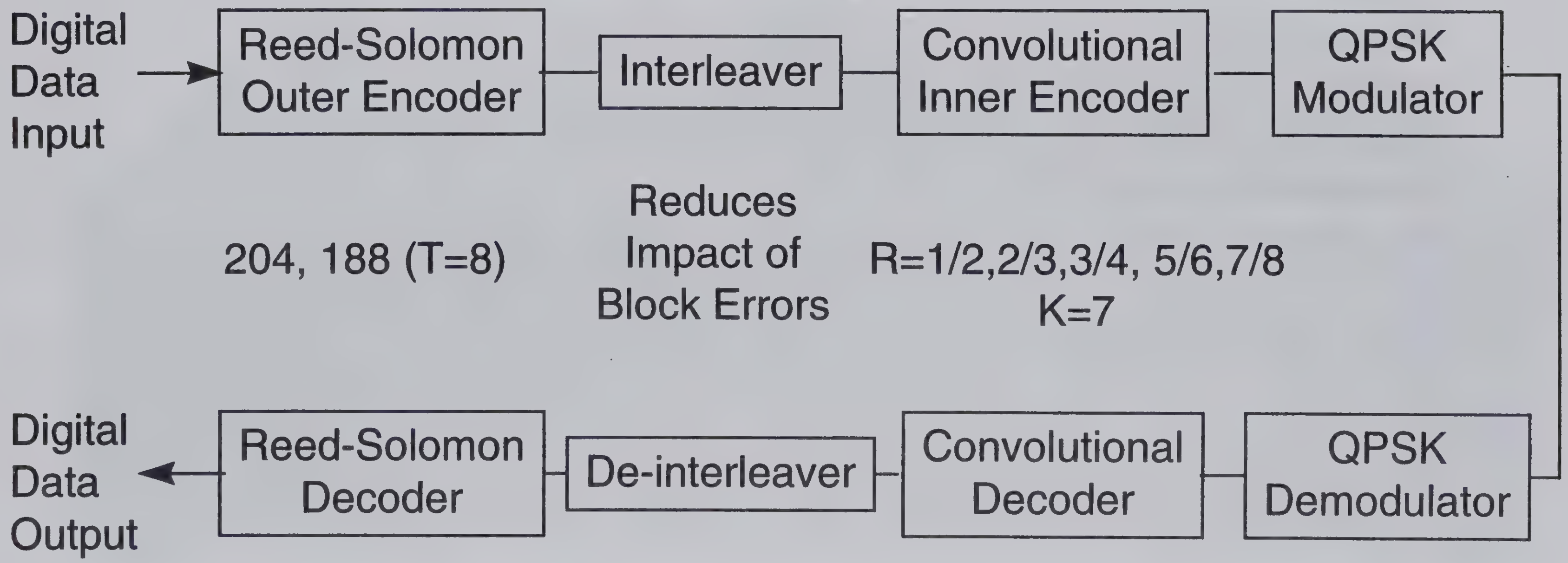
DVB Standard

- **Open standard**
- **Digital Television based on MPEG 2 principles**
- **Supports video, audio, and data**
- **Family of standards for different delivery methods**
  - **Satellite**
  - **Cable**
  - **Satellite master antenna TV (SMATV)**
  - **Terrestrial**
  - **Service information**
  - **Conditional access**

DVB-S: The Satellite Standard

- 26 to 72 MHz transponder bandwidth
    - Bit rates and bandwidth can be adjusted
- Single carrier with multiple digital channels
- Service components multiplexed on carrier
- Video, audio, and data inserted into standard payload packets (188 bytes)

Coding Scheme



Digital Data Input

Reed-Solomon Outer Encoder

Interleaver

Convolutional Inner Encoder

QPSK Modulator

204, 188 (T=8)

Reduces Impact of Block Errors

R=1/2,2/3,3/4, 5/6,7/8
K=7

Digital Data Output

Reed-Solomon Decoder

De-interleaver

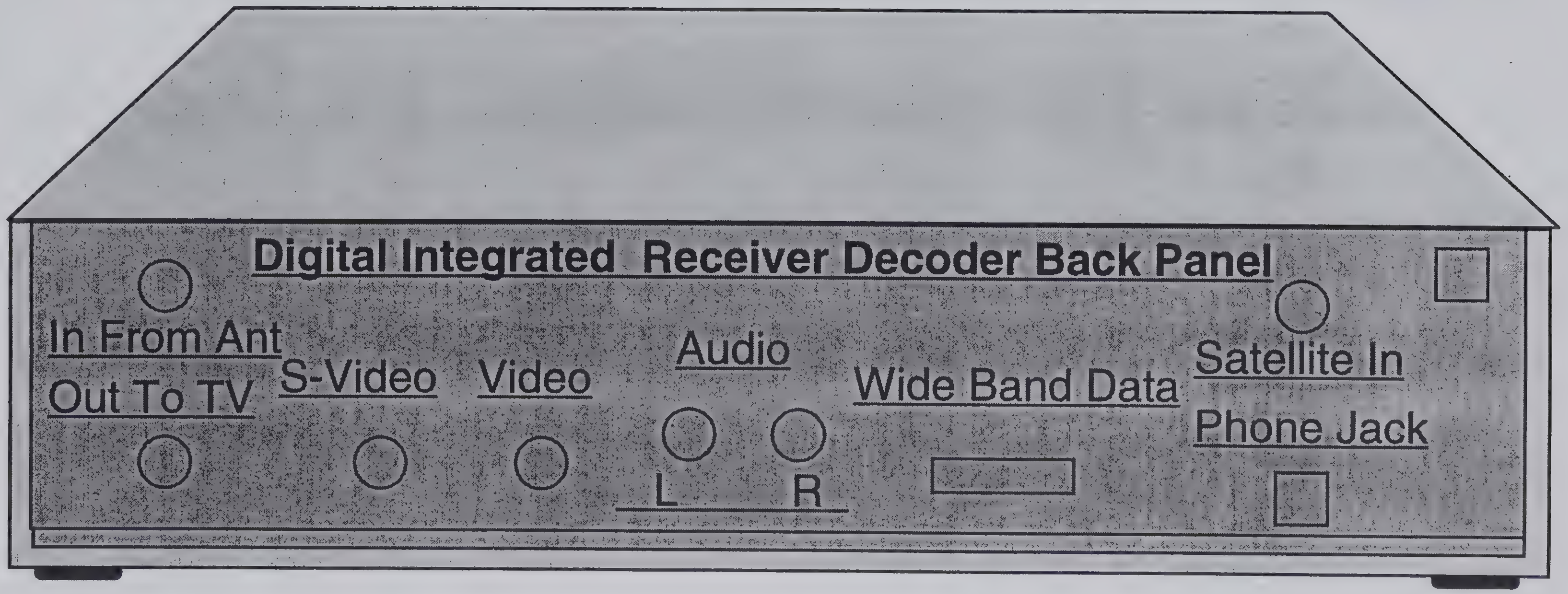
Convolutional Decoder

QPSK Demodulator

DVB Signal Characteristics

Transport Layer:	DVB (open standard)
Packet Size:	188 bytes
Payload Size:	184 bytes
Video Standard:	MPEG 2, Main Level, Main Profile
Transponder Data Rate:	Variable
FEC Inner Code:	Convolutional, R=1/2,2/3,3/4,5/6,7/8 K=7
FEC Outer Code:	Reed-Solomon 204, 188 (T=8)
Data Rate with FEC:	Variable
Modulation:	QPSK
Symbol Rate:	Variable
Channel Bandwidth:	26 to 72 MHz

DTH Receivers



Electronic Program Guide

- Allows user to select channel
- Allows user to see upcoming programs
- Allows user to see background information on program
- Raw program guide data sent over satellite link
- Receiver manufacturer develops custom program guide
- Video, audio, and data can be tied to a program guide channel

Conditional Access

- **Allows service provider to grant access to program content**
- **Uses smart card technology**
    - **Facilitates rapid/ low cost changeout if needed**
- **Regular broadcast of entitlement messages over the satellite link**
- **Supports pay-per-view functions**

DVB Conditional Access

- **Multicrypt**
  - **Puts intelligence/decoding directly on the smart card**
  - **Highly secure**
  - **Expensive to change**
  - **PCMCIA interface**
- **Simulcrypt**
  - **Delivers one program to different decoder groupings running different conditional access systems**
  - **Less secure**
  - **Inexpensive to change**

Commercial Satellite Communication Applications
Course No. 9SV109

Module 6
Telephone Service
October 24, 1997

Boeing Information, Space, & Defense Systems

Module Objectives / Assessments

What you can learn in this module:

- What are the characteristics of a telephone voice signal, both analog and digital.
- How multiple telephone signals are truncked together
- What are the characteristics of some of the mobile satellite telephone systems

How to measure your success:

- Can you give the bandwidth and sample rates for a telephone voice signal
- Can you describe the describe two multiplexing schemes for telephone truncking
- Can you identify three future suppliers of mobile telephone communications and what are the major differences in their approaches

Telephone Signal

Telephone Voice signal

- Bandwidth - 4 kHz
- SNR - 30 dB (Terrestrial)
- SNR - 50 dB (Satellite)

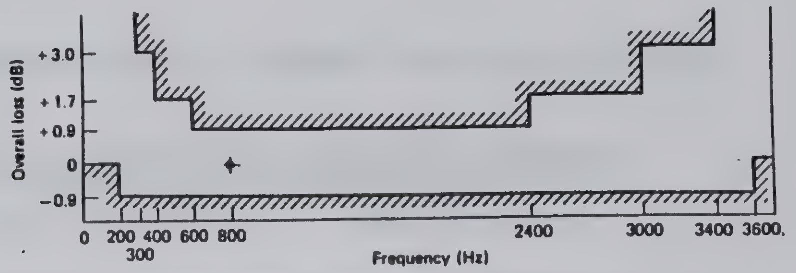


Figure 3.15a Permissible limits for the variation with frequency of the overall loss for any pair of channel transmitting and receiving equipments of one 12-channel terminal equipment. (From CCITT Rec. G.232; courtesy of ITU – CCITT.)

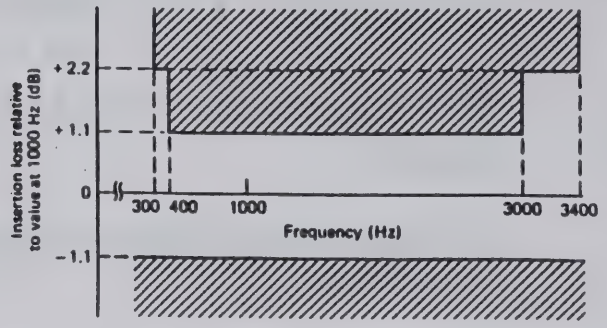
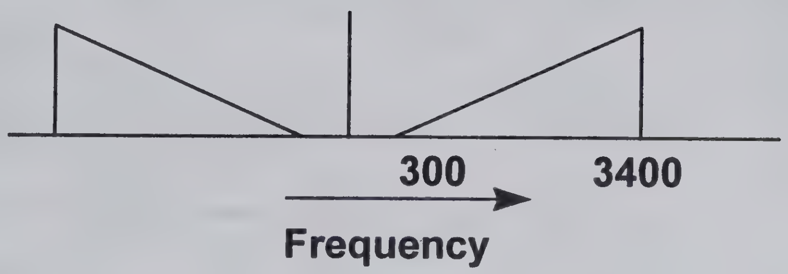


Figure 3.15b Insertion loss versus frequency characteristic for single long-haul reference voice band width link. (From MIL-STD-188-100.)

Voice Signal Representation

6- 3

- Baseband signal spectrum
  - Double sideband (DSB)



- Real signals have even spectrum
- Negative sideband contains same information as positive sideband
- Need to transmit only one sideband
  - Single-sideband (SSB)

Analog Multiplex Groups

6- 4

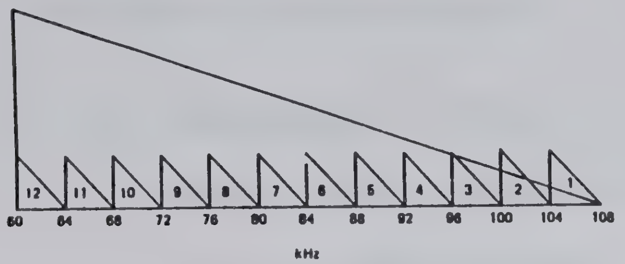


Figure 3.6 Standard CCITT group.

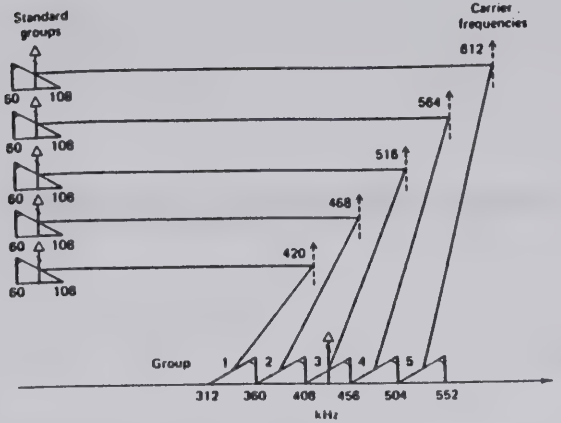


Figure 3.7 Formation of the standard CCITT supergroup. *Note*: Vertical arrows show group level regulating pilot tones (see Section 3.2.5). (From CCITT G.233; courtesy of ITU - CCITT.)

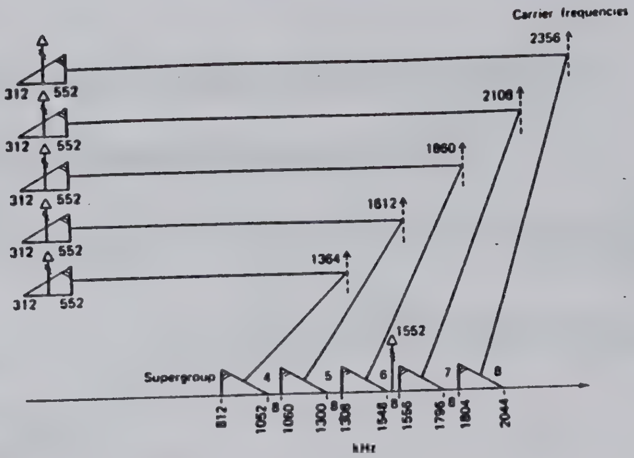


Figure 3.8 Formation of the standard CCITT mastergroup. (From CCITT Rec. G.233; courtesy of ITU - CCITT.)

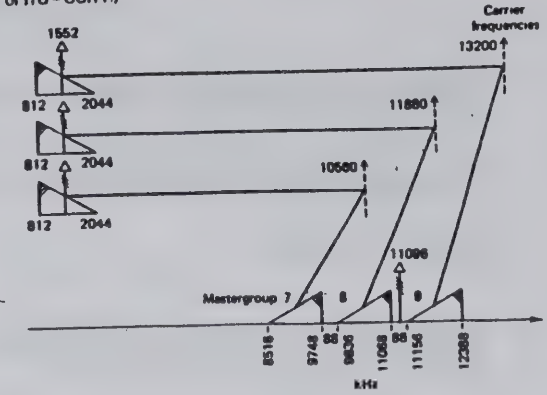


Figure 3.9 Formation of the standard CCITT supermastergroup. (From CCITT Rec. G.233; courtesy of ITU - CCITT.)

Analog Multiplex Hierarchy

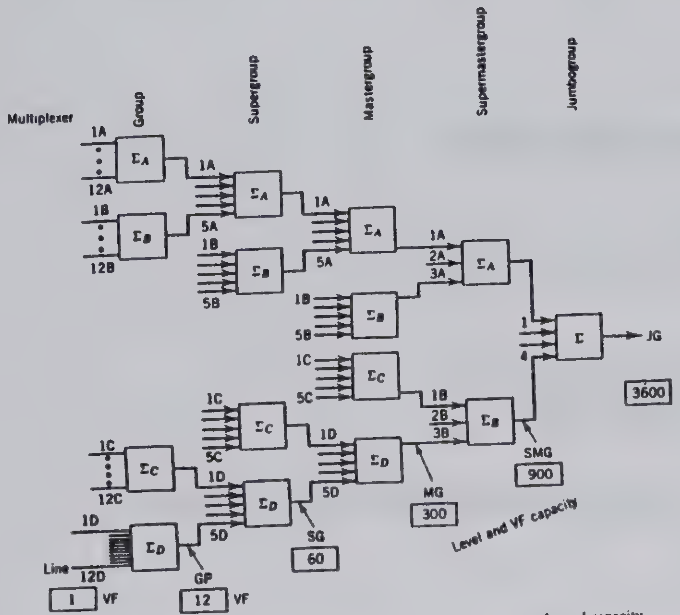


FIGURE 2.1 Analog hierarchy for North America: VF, voice frequency channel capacity.

TABLE 2.2 Analog Building Blocks[a]

Quantity Name	Abbreviation	Equivalent Voice Channels	Bandwidth (kHz)	Bands Occupied (kHz)	
				Intelsat	Terrestrial
Voice frequency pregroup	VF	1	3-4	—	0.300-3.400
Group (12 VF)	GP	12	48 or 56	—	12-60 or 60-108
Supergroup					
5GP	SG	60	240	12-252	12-252, 60-300, or 312-552
10GP	SG	120	480	—	12-552 or 60-552
Basic	SG	300	1200	12-1300[b]	60-1364 or 812-2044
Mastergroup	MG	600	2400	12-2540[b]	60-2792 or 60-2540
Basic supermastergroup	SMG	900	3600	12-4028[b]	8516-12,388
		900	3716		312-4028
		960	4227	12-4028[b]	60-4287 or 8516-12,388
Jumbogroup	JG	3600	—	—	564-17,548
Video North American, Japan (NTSC)	—	—	4200		60-4287
Most of rest of world	—	—	6000		6 MHz
Data under voice (DUV), SG or MG/1.544 Mbits/sec (adds a SG to an existing MG)		—	—		312-2044

[a] Underline denotes preferred quantities.

[b] Bands occupied for 312, 612, 972, and 972 channels, respectively.

Frequency Modulation

6- 6

- Frequency modulation is commonly used for analog satellite channels
    - Satellites are basically power limited systems
    - FM can trade power for bandwidth
    - FM is constant-amplitude signal
    - Information is contained in zero crossings
    - It can tolerate more non-linearity in the transmitter than can amplitude modulation

SNR Improvement

6- 7

$$\frac{S}{N} = \frac{C}{N}\, 3\,(1+\beta)\,\beta^2$$

β is the modulation index

For wideband FM, $\beta \gg 1$, SNR > CNR

Typical Modulation index, $\beta = 9$

$$\frac{S}{N} = 2430\,\frac{C}{N} \qquad \text{33.8 dB improvement}$$

CNR = 17.2 dB SNR = 51 dB

Digital Voice

- **Conversion of continuous time, continuous amplitude signal to discrete time, discrete amplitude data**
- **Sample Rate**
  - **Nyquist rule - sample rate must be 2x the highest frequency contained in the analog signal**
  - **Bandwidth - 4 kHz, Sample rate 8 kHz**
- **Quantization**
  - **SNR is dependent on quantization levels**
  - **12 to 13 bits normally required for acceptable quality voice**
- **Data Rate, 8 kHz x 12 bits = 96 kb/s**

Companding

- Companding universally used
  - Human hearing appears to have an AGC which adjusts its sensitivity to the average sound level
  - When sound level is high, large quantization errors are not detected
  - Use small quantization levels for small signals, and large quantization levels for large signals
  - Two standard companding schemes are used
    - μ–Law, North American standard
    - – A-Law, European standard
- Reduce quantization to 8 bits, and data rate to 64 kb/s

μ-Law Companding

$$|Y| = \frac{\log(1 + \mu\,|x|)}{\log(1 + \mu)}$$

$\mu = 255$

Y is output level

x is input level

SNR improvement is 30 dB

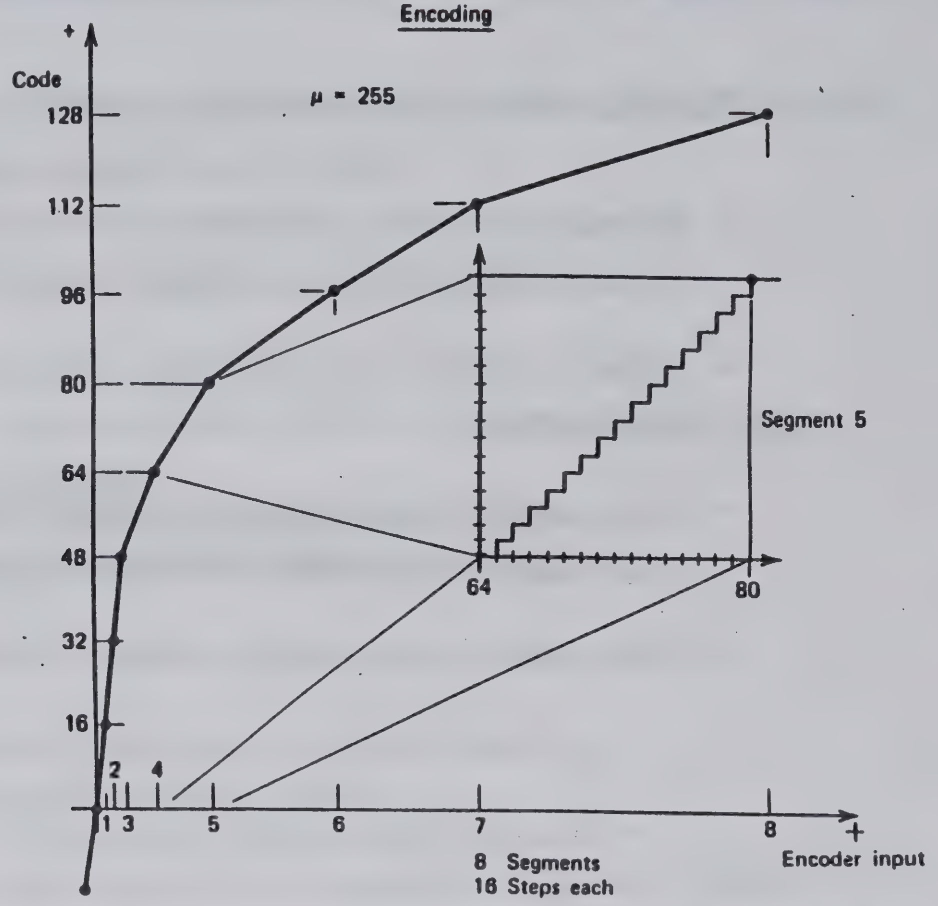


Figure 3.38 Positive portion of the segmented approximation of the μ-law quantizing curve used in the North American DS1 PCM channelizing equipment. (Courtesy of ITT Telecommunications, Raleigh, NC.)

Speech Compression

Transmit power is directly proportional to data rate

Power Reduction Table

Coding Technique	Data Rate	Power
POTS	64 kb/s	0 dB
CVSD	16 kb/s	-6 dB
CELP/MELP/VSELP	4.8 kb/s	-11.2 dB
LPC-10	2.4 kb/s	-14.3 dB
7-bit ACSII Text	150 b/s	-26.3 dB
3-bit Text	64.3 b/s	-30 dB

Time Division Multiplex

- Multiplexes samples from many different sources into one data stream

- Two basic multiplex schemes

  - T1 - North American   24 channels - 1.544 Mb/s
  - Cept30+2 - European   30 channels - 2.048 Mb/s

T1 - D1D (CCITT)

- 125 usec frame (8 kHz)
- 24 channels * 8 bits/channel + 1 sync bit = 193 bits
- 193 bits / 12 usec = 1.544 Mb/s
- 8th bit of all channels in frames 6 and 12 used for signaling
- Unique word frame synchronization pattern

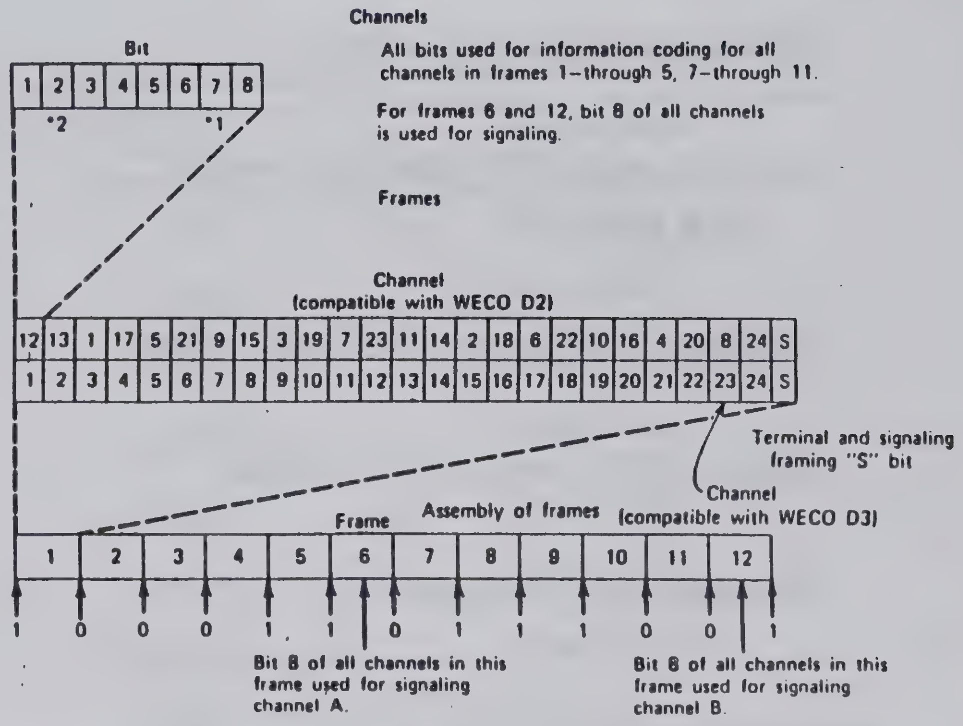

Channels
All bits used for information coding for all channels in frames 1–through 5, 7–through 11.
For frames 6 and 12, bit 8 of all channels is used for signaling.
Frames
Bit
1 2 3 4 5 6 7 8
*2
*1
Channel
(compatible with WECO D2)
12 13 1 17 5 21 9 15 3 19 7 23 11 14 2 18 6 22 10 16 4 20 8 24 S
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 S
Terminal and signaling framing "S" bit
Channel
(compatible with WECO D3)
Frame
Assembly of frames
1 2 3 4 5 6 7 8 9 10 11 12
1 0 0 0 1 1 0 1 1 1 0 0 1
Bit 8 of all channels in this frame used for signaling channel A.
Bit 8 of all channels in this frame used for signaling channel B.

Figure 3.40 Frame structure of the North American (AT&T) D1D (DS1) PCM system for the channel bank. Note the bit "robbing" technique used on each sixth frame to provide signaling information. *Notes*: (1) If bits 1 – 6 and 8 are 0, then bit 7 is transmitted as 1. (2) Bit 2 is transmitted as 0 on all channels for transmission if end-to-end alarm. (3) Composite pattern 000110111001, etc. (Ref. 16, courtesy of ITT Telecommunications, Raleigh, NC.)

CEPT 30+2 (E1)

125 usec frame (8 kHz)

32 channels 8 8 bits/channel =
256 bits

256 bits / 125 usec = 2.048 Mb/s

Channel 0 - synchronization

Channel 16 - Signaling

Digital Multiplex Hierarchy

TABLE 7. US DIGITAL-NETWORK COMMON-CARRIER MULTIPLEX LEVELS

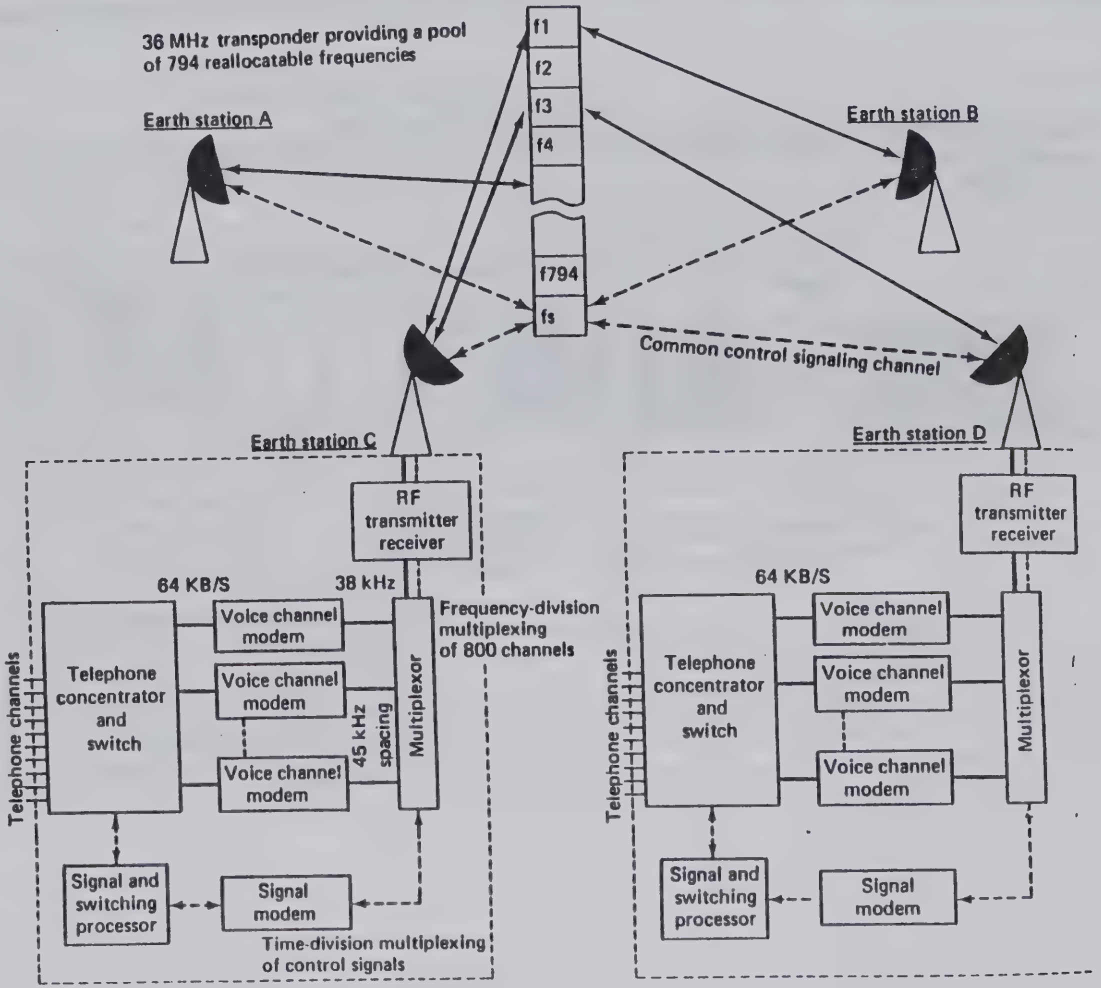
Name	Time Slots (64 kb/s each)	Line Bit Rate (Mb/s)	Transmission Media
DS1	24	1.544	Wire Pairs
DS1C	48	3.152	Wire Pairs
DS2	96	6.312	Wire Pairs, Fiber
DS3	672	44.736	Radio, Fiber
DS3C	1344	90.254	Radio, Fiber
DS4E	2016	139.264	Radio, Fiber, Coaxial Cable
DS4	4032	274.176	Coaxial Cable
DS432	6048	432.00	Fiber

Demand Assigned Network

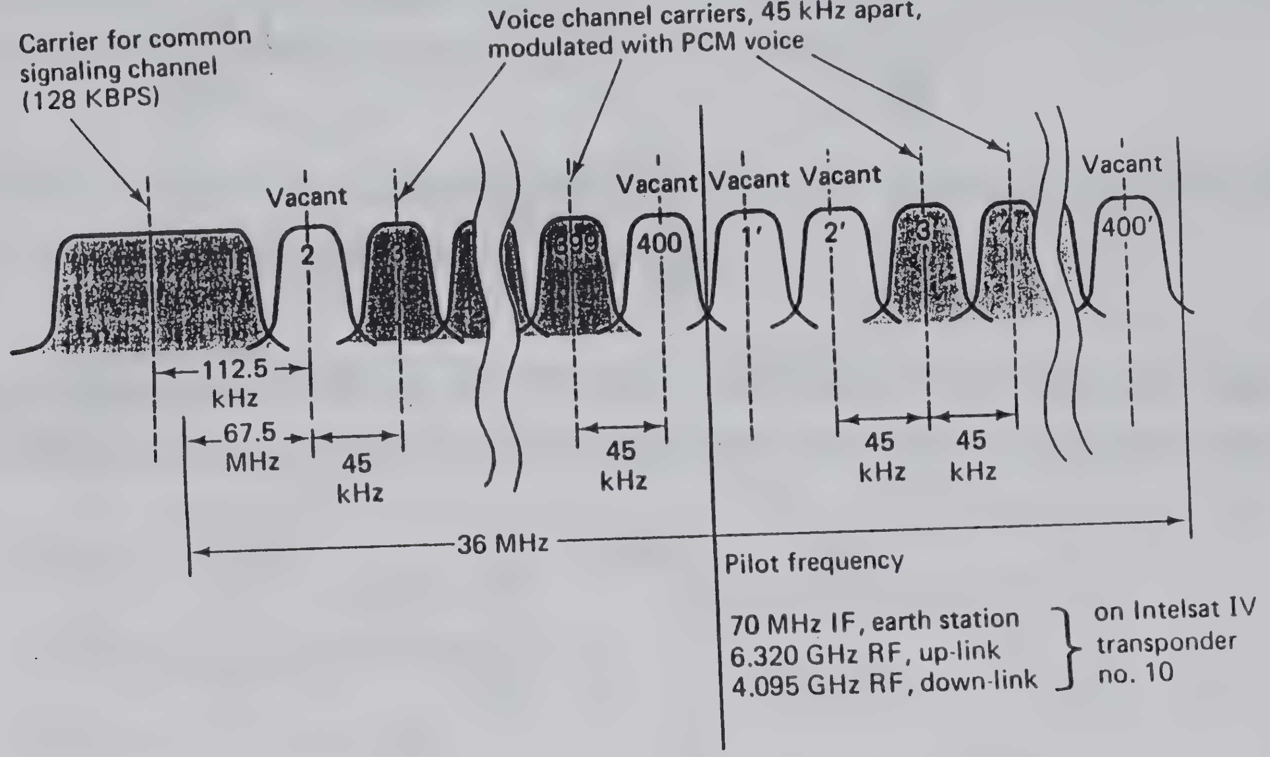
- Provides efficient service to light traffic links based on timely need rather than preassigned trunking
- Utilizes satellite capacity efficiently by assigning circuits individually on demand
- One implementation is SPADE , Single-channel-per-carrier, PCM multiple-Access, Demand assignment Equipment
    - FDMA
    - Demand assigned access
    - 794 voice channels
    - 1 common signaling channel

Spade System

6- 17

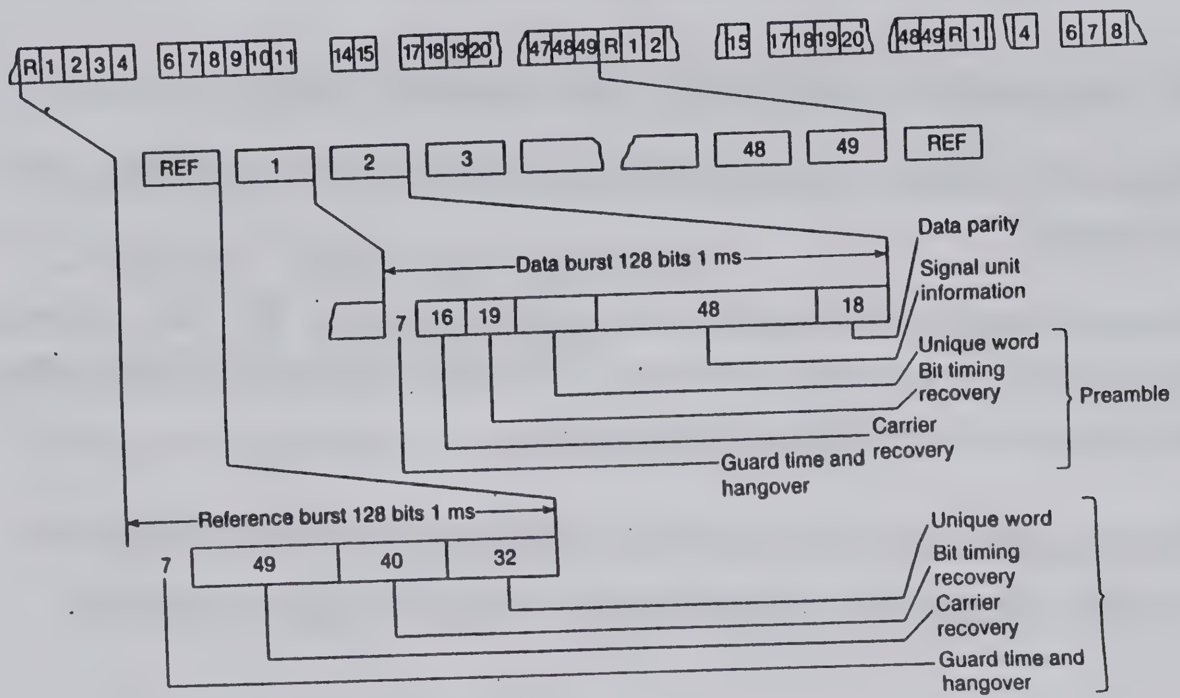

36 MHz transponder providing a pool
of 794 reallocatable frequencies
f1
f2
f3
f4
f794
fs
Earth station A
Earth station B
Common control signaling channel
Earth station C
Earth station D
RF transmitter receiver
64 KB/S
38 kHz
Voice channel modem
Frequency-division multiplexing of 800 channels
Telephone channels
Telephone concentrator and switch
45 kHz spacing
Multiplexor
Signal and switching processor
Signal modem
Time-division multiplexing of control signals

Spade Frequency Assignments



Common Signaling Channel

6- 19



Control Signaling

- **Decentralized control using common signaling channel**
    - **‘A’ requests to send to ‘B’ on channel 3**
    - **When ‘B’ gets request, if channel 3 is still available, ‘B’ tells ‘A’ to begin**
    - **Occasionally, before the request reaches ‘B’, the channel will be allocated to another station. ‘A’ will detect the allocation and will request a different channel.**
- **Assignments are requested randomly from a pool of available channels to minimize duplicate requests**

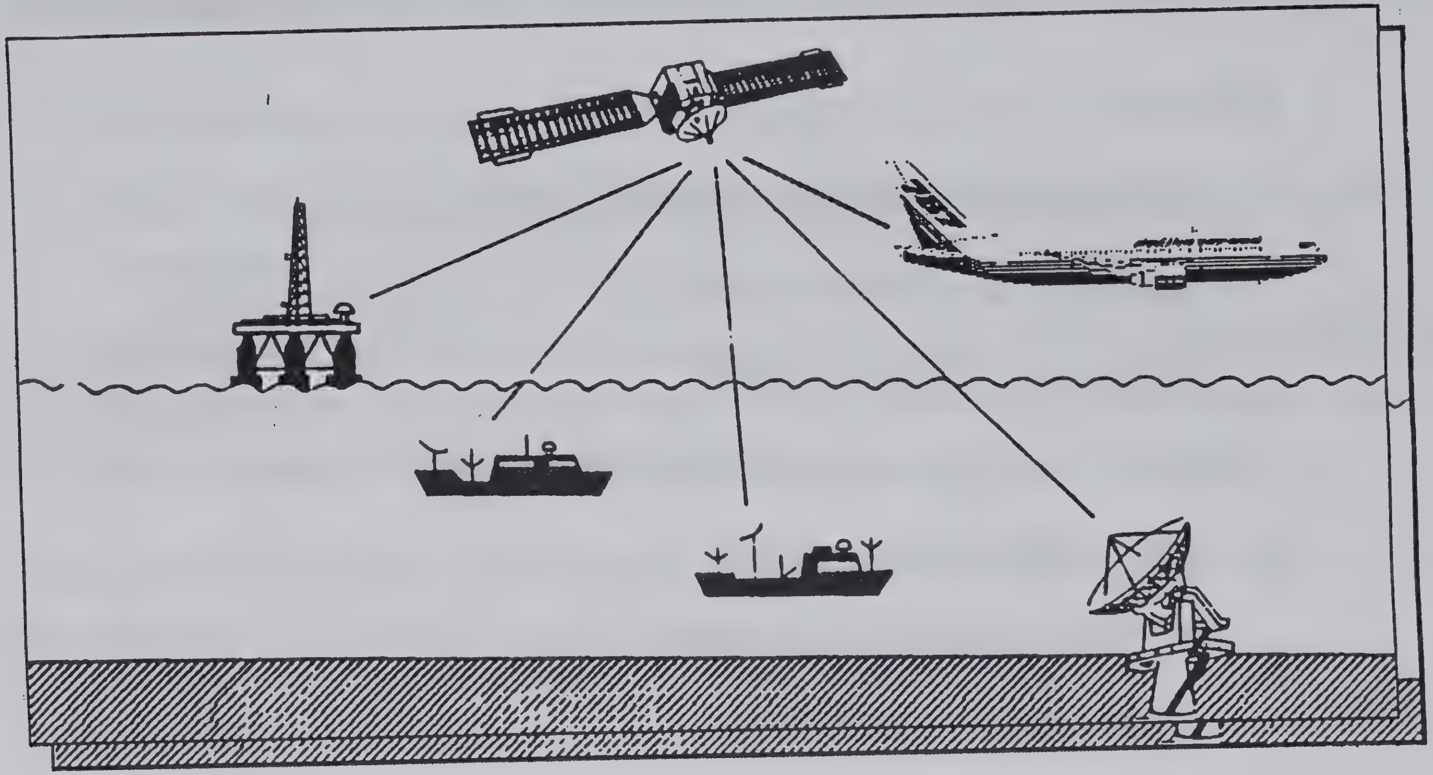
Mobile Satellite Service
MSS

Many different system architectures are used or planned

- **Different orbits**
  - **INMARSAT, AMSC use GEO orbit**
  - **Iridium, Globalstar use LEO**
  - **Odyssey, ICO use MEO**
- **Different multiple-access schemes used**
  - **INMARSAT uses FDMA**
  - **Iridium uses FDMA/TDMA**
  - **Globalstar uses CDMA**

No clear best architecture

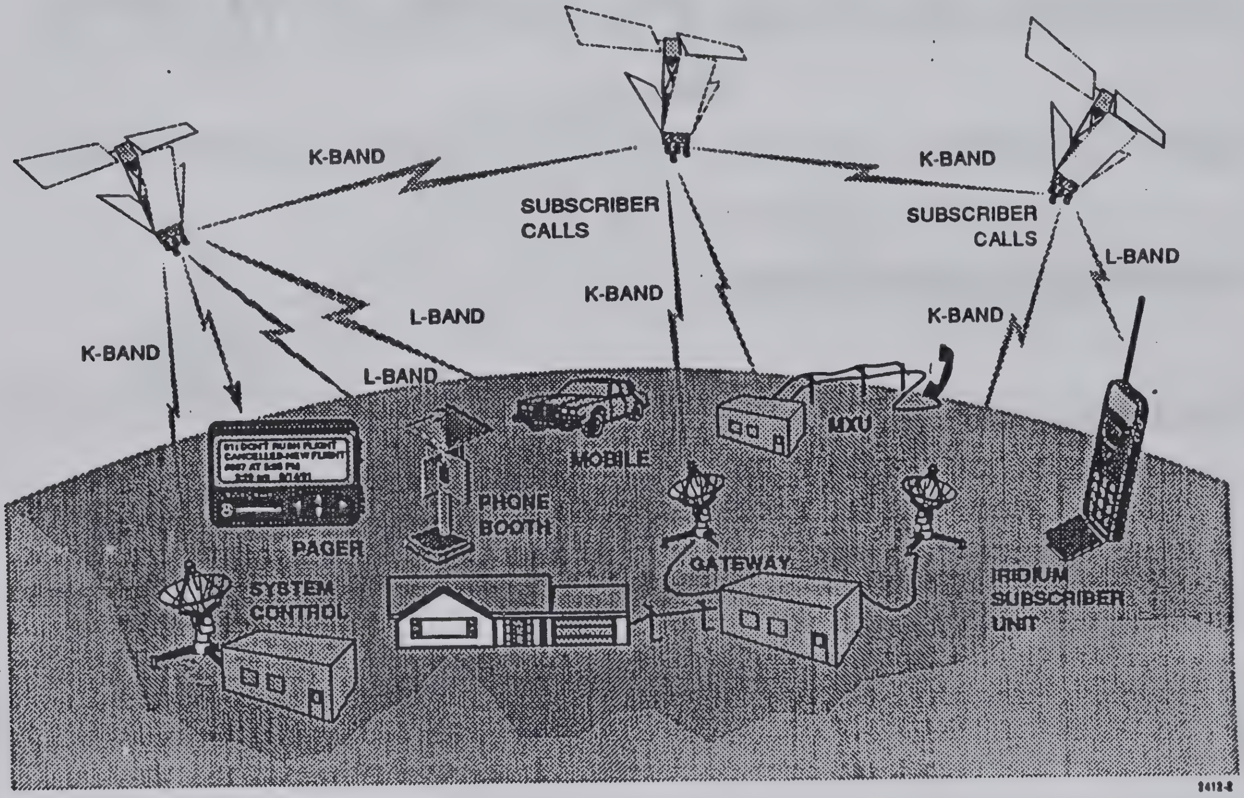
INMARSAT Network



INMARSAT Characteristics

- **4 locations at GEO, 64.5° E, 15.5° W, 55° W, 178° E**
- **Earth Coverage beams and some large spot beams**
- **FDMA multiple-access**
- **Bent-pipe transponder**
- **Variety of services**
  - **Paging, data, voice**
  - **300 b/s to 64 kb/s**
- **Transportable user equipment (not hand-held)**

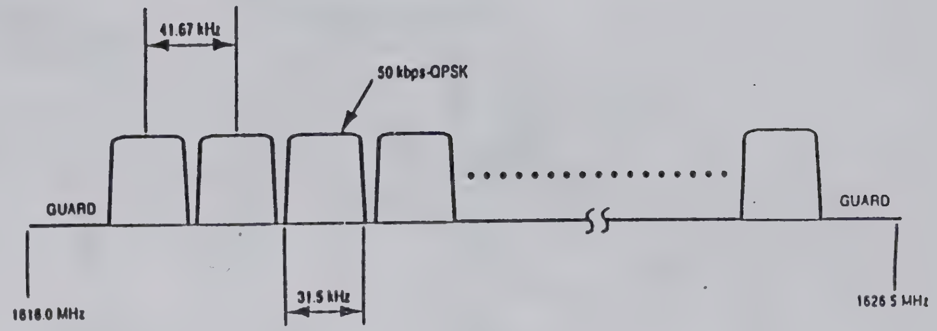
Iridium Network

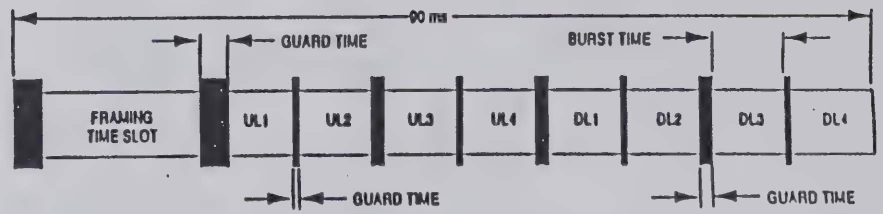


Iridium Characteristics

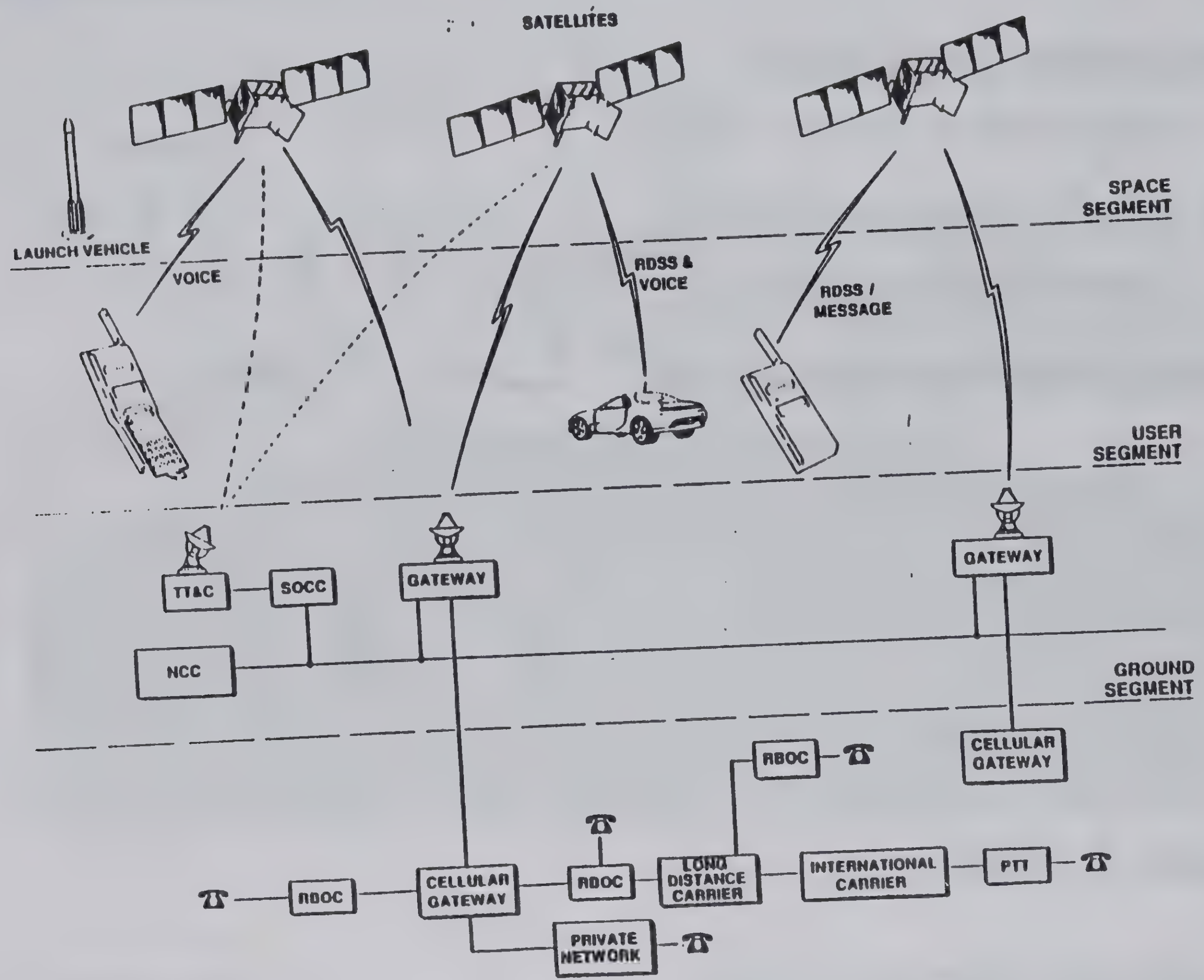
6- 25

- 66 sateilite constellation
  - Polar orbit at 778 km altitude
- 48 overlapping spot beams
  - 12-cell frequency reuse
- FDMA/TDMA Multiple-access
- Demod/Remod transponder
- 4 Crosslinks per satellite
- Voice - 4.8 kb/s
- Data - 2.4 kb/s
- Handheld user equipment





Globalstar Network



Globalstar Characteristics

- **48 satellites**
  - **52° inclined orbit at 1389 km**
- **Spot beam architecture**
- **FDMA/CDMA multiple-access**
- **Bent-pipe transponder**
- **Voice - 4.8 kb/s**
- **Data - 1.2 to 9.6 kb/s**
- **Handheld user equipment**

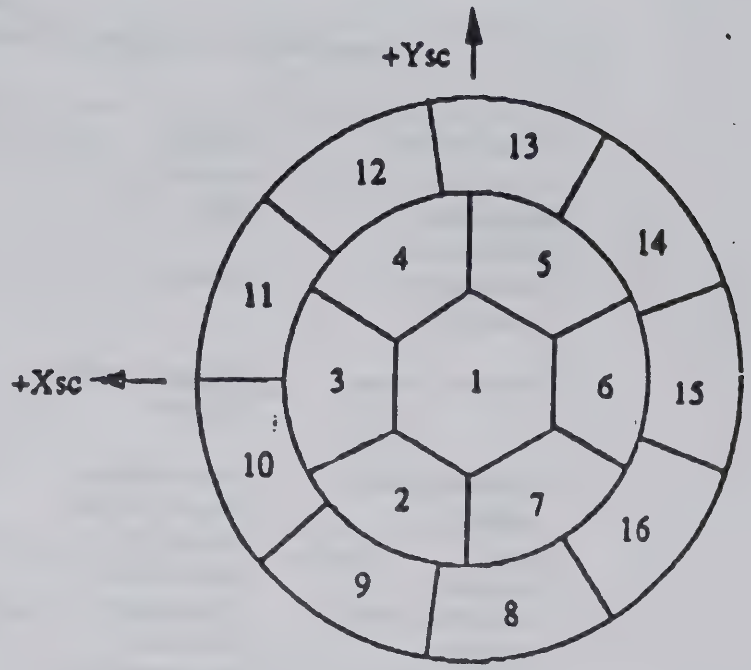


Figure 4-B: Individual Service Beam Coverage Pattern
(View from Satellite, looking at Earth Nadir)

FDMA, TDMA, CDMA Comparison

Table 9.6
A Comparison of the System Characteristics of Multiple Access Techniques

Characteristic	*FDMA*	*TDMA*	*CDMA*
Bandwidth utilization	SCPC	MCPC, partial allocation	SCPC, partial or full allocation
Interference rejection	Limited	Limited, with frequency hopping	Can suppress interference, up to noise limit
Frequency reuse	Requires 7-cell pattern	Requires 7-cell pattern	Zero to 4 cell reuse possible, up to noise limit
Intermodulation effects	Most sensitive (most backoff required)	Less sensitive (less backoff required)	Least sensitive (least backoff required)
Doppler frequency shift	Bandwidth limiting	Burst-time limiting	Removed by receiver
Spectrum flexibility	Uses least bandwidth per carrier	Moderate bandwidth use per carrier	Largest demand for contiguous segment
Capacity	Basic capacity available	Can provide capacity improvement through hopping	Capacity indeterminate due to loading unknowns

Orbits and Number of Satellites

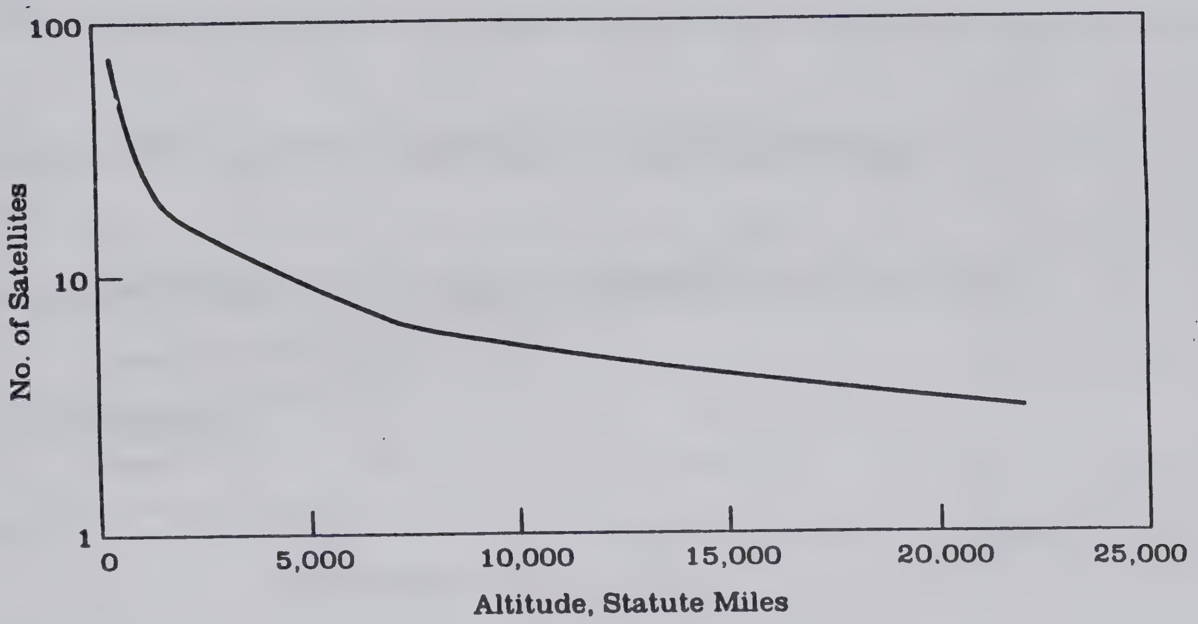


Figure 9.20 Theoretical number of satellites required for continuous coverage, shown as a function of altitude in statute miles. Note the logarithmic scale.

Orbits and Investment Costs

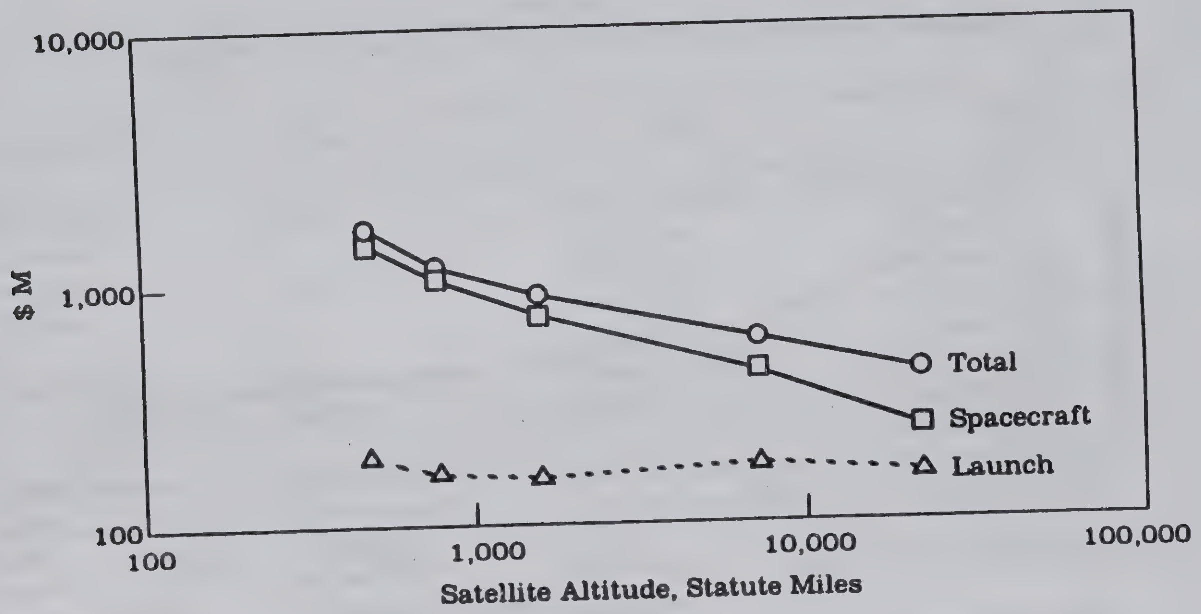


Figure 9.21 An evaluation of the relative investment cost requirement for different implementations of a global MSS system (space segment only). The three curves represent (1) the total investment needed to achieve operation, (2) the cost of the spacecraft alone (e.g., construction only), and (3) the cost of launching the constellation. The cost is driven by the number of spacecraft as the total launch cost is relatively constant across the different altitudes.

Telephone Service Summary

- **Analog and digital characteristics of voice communications**
- **Analog and digital multiplex and trunking**
- **Demand-assigned access networks (SPADE)**
- **MSS networks**

Commercial Satellite Communication Applications
Course No. 9SV109

Module 7
Data/Multimedia Services

October 24, 1997

Boeing Information, Space, & Defense Systems

Module Objectives / Assessments

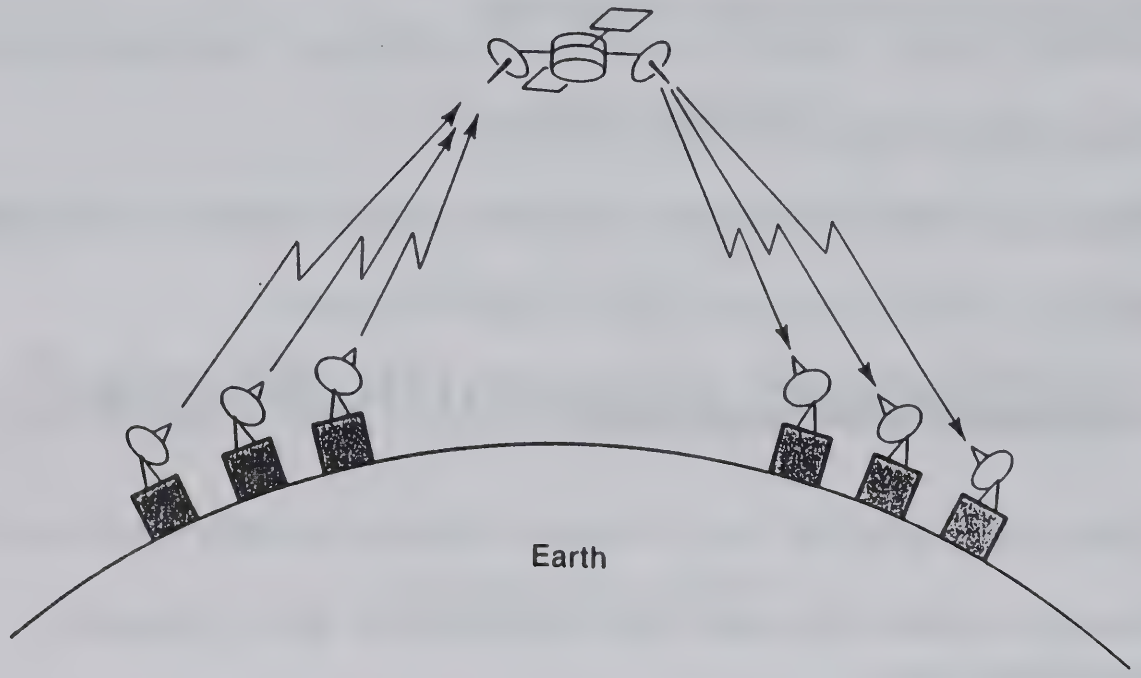
What you can learn in this module:

- How data networks are modeled
- What are some common satellite data network architectures
- What a VSAT system is and how it works

How to measure your success:

- Can you describe the principle characteristics of the OSI model
- Can you describe two typical satellite data network architectures
- What is the primary transport protocol used in a typical VSAT network

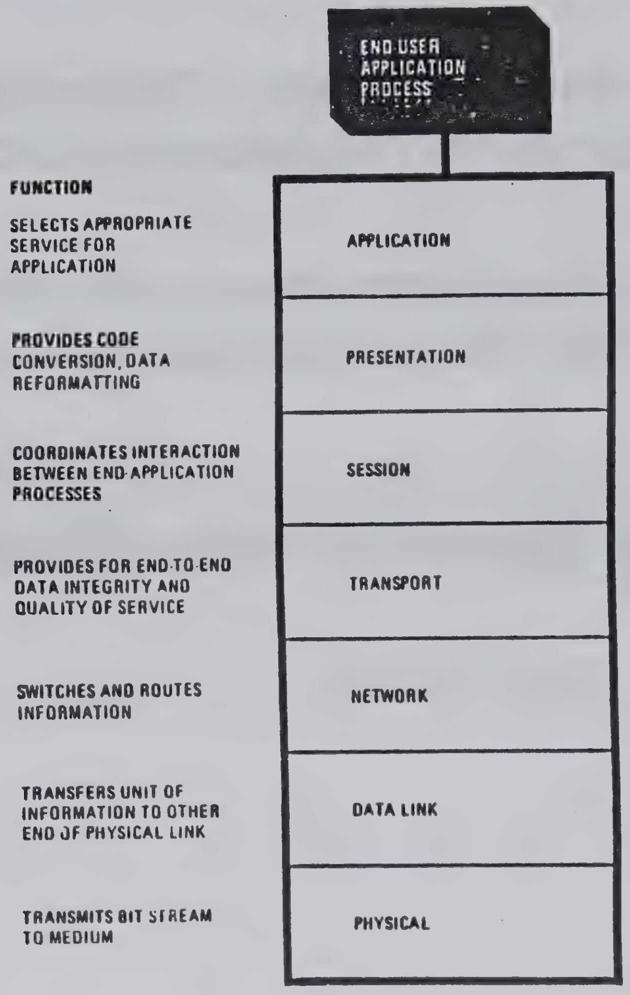
Data Networks



OSI Model

- Open Systems Interconnection (OSI) model defined by the International Standards Organization (ISO)
- The purpose is to separate the communications problem into several layers that can be implemented independent of other layers
- Model serves as a guide for interface standards definition
- ISO/IEC 7498-1, ITU-T X.200

Layers



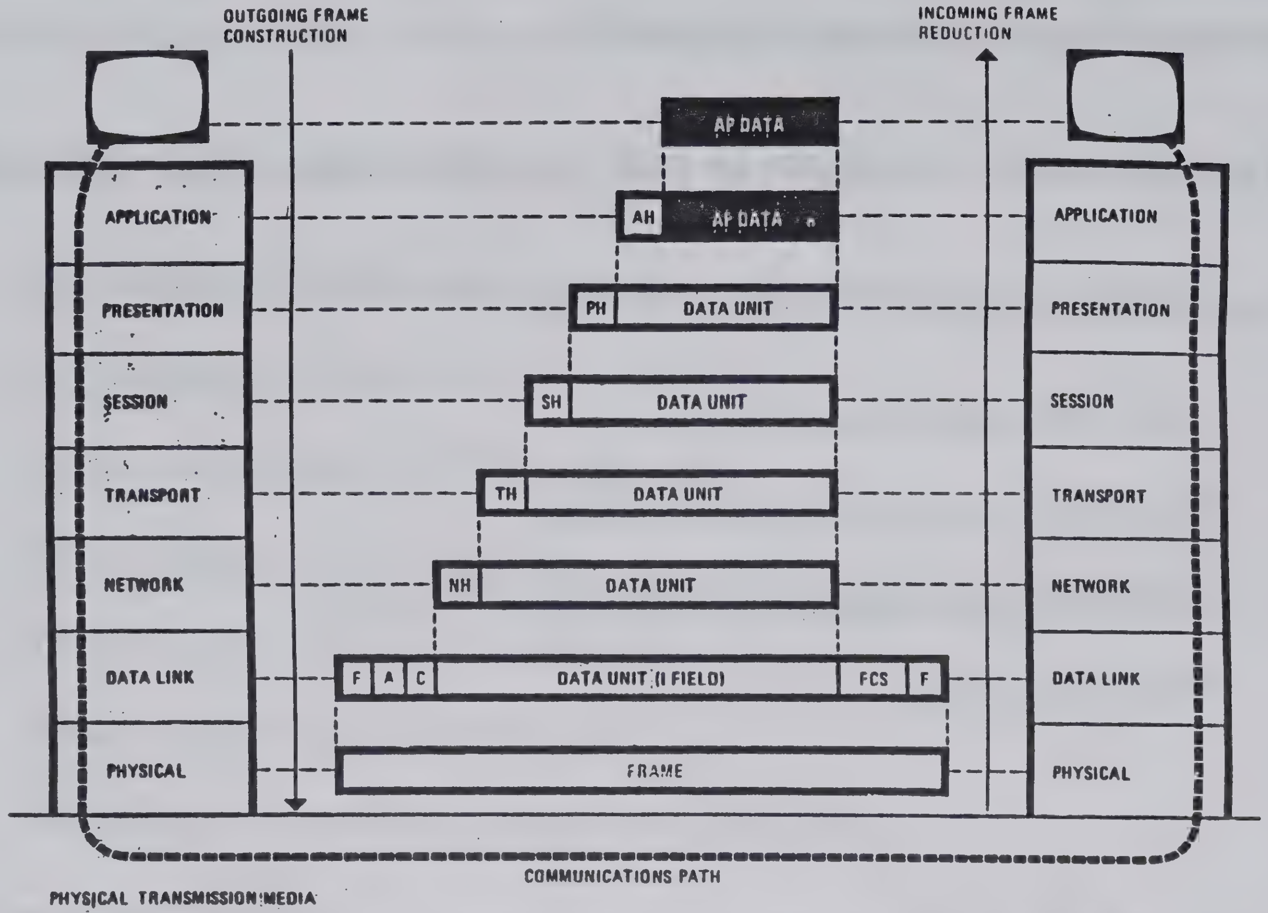
END USER APPLICATION PROCESS

FUNCTION	
SELECTS APPROPRIATE SERVICE FOR APPLICATION	APPLICATION
PROVIDES CODE CONVERSION, DATA REFORMATTING	PRESENTATION
COORDINATES INTERACTION BETWEEN END-APPLICATION PROCESSES	SESSION
PROVIDES FOR END-TO-END DATA INTEGRITY AND QUALITY OF SERVICE	TRANSPORT
SWITCHES AND ROUTES INFORMATION	NETWORK
TRANSFERS UNIT OF INFORMATION TO OTHER END OF PHYSICAL LINK	DATA LINK
TRANSMITS BIT STREAM TO MEDIUM	PHYSICAL

Peer-to-Peer Communications

7- 5

5. Frame construction. *The application-process data unit is appended with a control header (containing information defined in the peer protocol) by each of the seven functional layers. The original data, combined with the header of a specific layer, is viewed by the subjoining layer as an integral data unit.*



Physical Layer

- **Provides for transmission and reception of bit streams across the transmission media**
- **Transmission medium is not considered part of the layer**
- **Functions occurring in this layer**
  - **Link activation/deactivation**
  - **Transmission (bit, symbol, etc.)**
  - **Data unit multiplexing (including framing)**
  - **Fault detection**

Data Link Layer

- **Provides for the transfer of data between adjacent nodes or connection points either by dedicated or multiple-access link**
- **Functions include**
  - **Data link establishment and deactivation (addressing)**
  - **Link data-unit transmission (block)**
  - **Data unit splitting (VTC example)**
  - **Data unit synchronization**
  - **Error detection and correction**
  - **Flow control across the link**
  - **Handling of multiple physical layer links**

Network Layer

- **Responsible for routing information end-to-end in a network**
- **Functions include**
    - **Routing and switching**
    - **Message blocking**
    - **Higher forms of error control**
    - **Sequencing of data (selective repeat ARQ example)**
    - **Association of network addresses with physical address**
    - **Expedited data transfer**

Transport Layer

- Provides transparent transfer of data between session layers and reliable & cost effective data transfer
- Functions include
    - Even higher levels of error control
    - Message disassembly into transmission units
    - Flow control at the network level
    - Prioritization
    - Network management functions

Session Layer

- **Provides services to establish session connection between presentations and support the orderly data exchange interactions**

- **Functions include**
  - **Session establishment**
  - **Buffering received data pending complete message assembly**
  - **Recovery of abnormally terminated session**

Presentation Layer

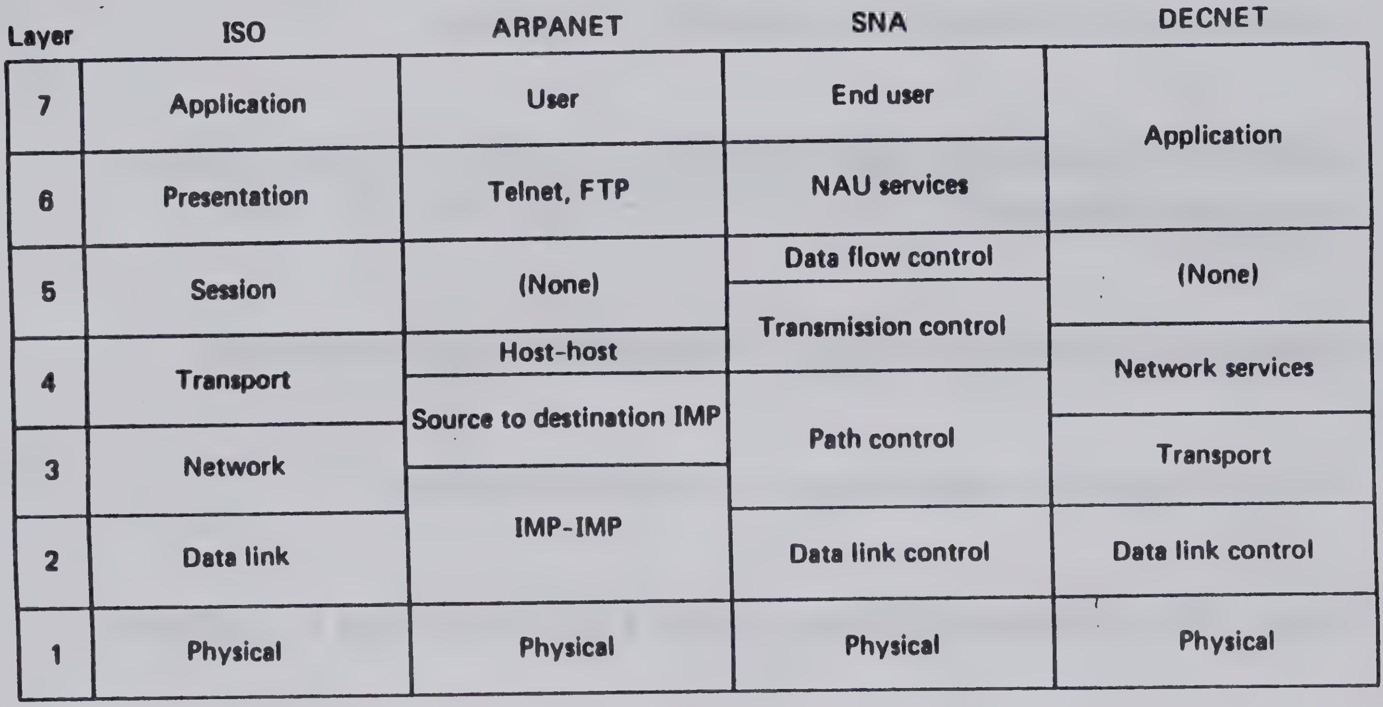
- **Provides for representation of information**
- **Functions include**
  - **Code, character set, and format conversions**
  - **Encryption**
  - **Negotiation of transfer syntax**

Application Layer

- **Responsible for managing the relationship between the communication process and the application process**
- **Functions include**
  - **Determination of priorities**
  - **Determination of privacy mechanisms**
  - **Determination of authentication and validation procedures**

Comparison of Layered Systems

7- 13



Layer	ISO	ARPANET	SNA	DECNET
7	Application	User	End user	Application
6	Presentation	Telnet, FTP	NAU services	
5	Session	(None)	Data flow control Transmission control	(None)
4	Transport	Host-host Source to destination IMP	Path control	Network services
3	Network			Transport
2	Data link	IMP-IMP	Data link control	Data link control
1	Physical	Physical	Physical	Physical

Fig. 1-8. Approximate correspondences between the various networks.

OSI Summary

- Layered architecture model, 7 layers
- Used as basis for definition of network interface specifications
- Interface between layer N and N+1 is specified
- Peer-layer to peer-layer communication
- Not all systems follow exact OSI layering structure

TT&C Example of OSI Structure

Consultative Committee for Space Data Systems

REPORT CONCERNING SPACE
DATA SYSTEM STANDARDS

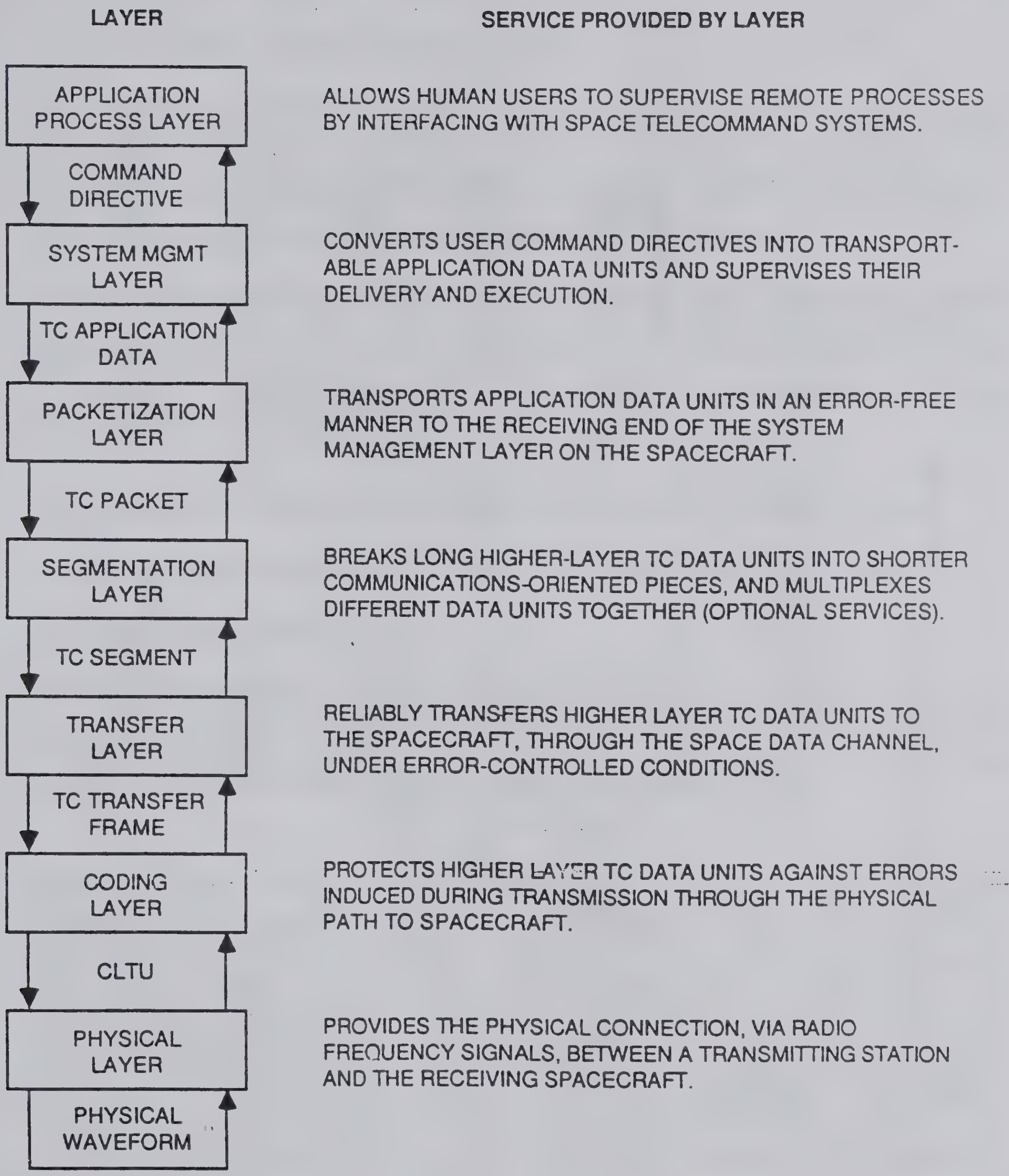
TELECOMMAND

SUMMARY OF CONCEPT AND SERVICE

CCSDS 200.0-G-6

GREEN BOOK

JANUARY 1987



ALLOWS HUMAN USERS TO SUPERVISE REMOTE PROCESSES BY INTERFACING WITH SPACE TELECOMMAND SYSTEMS.

CONVERTS USER COMMAND DIRECTIVES INTO TRANSPORTABLE APPLICATION DATA UNITS AND SUPERVISES THEIR DELIVERY AND EXECUTION.

TRANSPORTS APPLICATION DATA UNITS IN AN ERROR-FREE MANNER TO THE RECEIVING END OF THE SYSTEM MANAGEMENT LAYER ON THE SPACECRAFT.

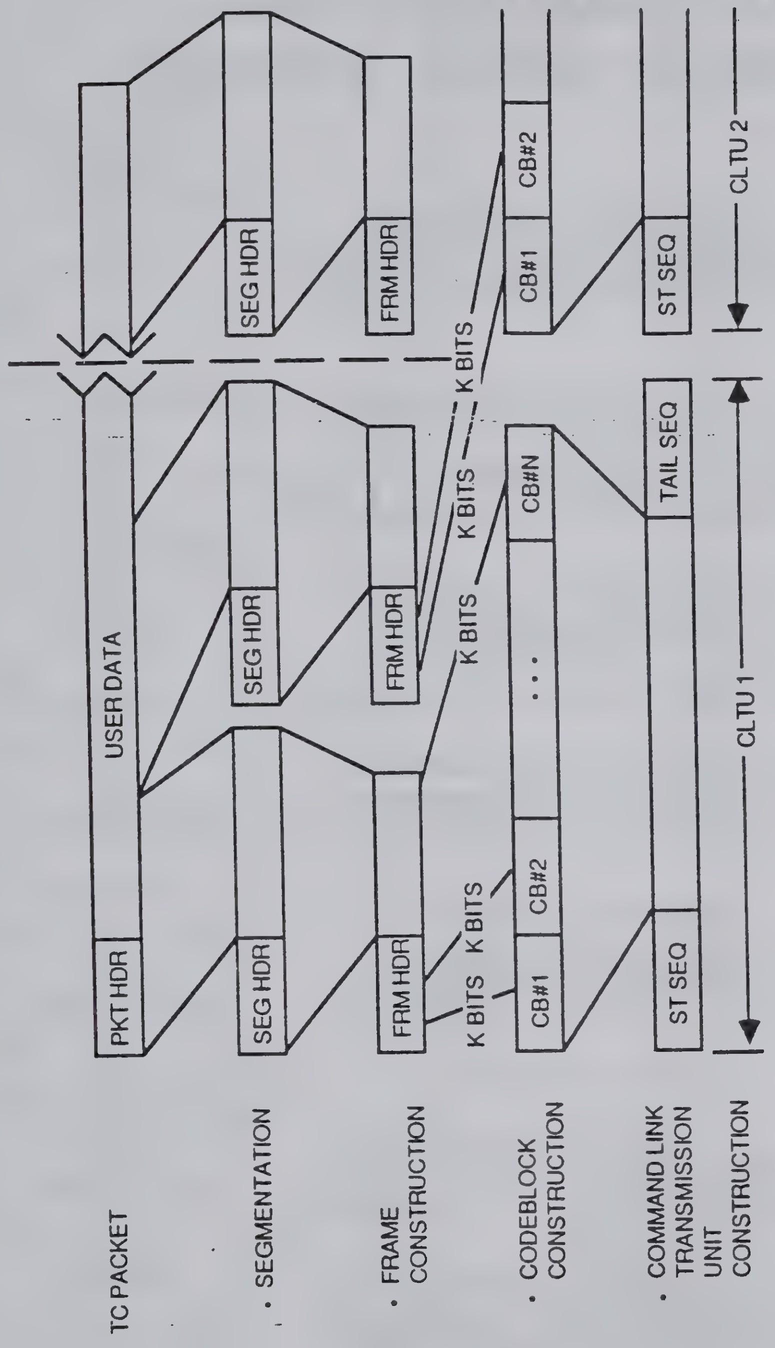
BREAKS LONG HIGHER-LAYER TC DATA UNITS INTO SHORTER COMMUNICATIONS-ORIENTED PIECES, AND MULTIPLEXES DIFFERENT DATA UNITS TOGETHER (OPTIONAL SERVICES).

RELIABLY TRANSFERS HIGHER LAYER TC DATA UNITS TO THE SPACECRAFT, THROUGH THE SPACE DATA CHANNEL, UNDER ERROR-CONTROLLED CONDITIONS.

PROTECTS HIGHER LAYER TC DATA UNITS AGAINST ERRORS INDUCED DURING TRANSMISSION THROUGH THE PHYSICAL PATH TO SPACECRAFT.

PROVIDES THE PHYSICAL CONNECTION, VIA RADIO FREQUENCY SIGNALS, BETWEEN A TRANSMITTING STATION AND THE RECEIVING SPACECRAFT.

Figure 2-2: Layered Telecommand Service Model



NOTE: THE DATA FIELD OF EACH CLTU CONTAINS THE ENCODED REPRESENTATION OF ONE OR MORE TRANSFER FRAMES.

Figure 2-4: Telecommand Data Structures

3 CODING LAYER: STANDARD DATA STRUCTURES AND PROCEDURES

3.1 OVERVIEW OF THE CODING LAYER

The Coding layer establishes the reliable, error-controlled data channel through which user telecommand data bits may be transferred. The data are encoded to reduce the effects of noise in the Physical layer channel on the user data. A block code has been chosen to provide this protection. Synchronization for the codeblock and delimiting of the beginning of user data are provided by the Command Link Transmission Unit (CLTU) data structure.

Resolution of data ambiguity (sense of "1" and "0") when receiving the symbol stream shall be a service of the Coding layer. Data ambiguity may result from the modulation technique utilized in the Physical layer such as suppressed-carrier modulation. Ambiguity resolution techniques shall use inherent information in the symbol stream such as either the CLTU start sequence pattern or NRZ-M modulation.

3.2 STANDARD DATA STRUCTURES WITHIN THE CODING LAYER

The standard data structures within the Coding layer are the TC Codeblock and the CLTU.

3.2.1 TC CODEBLOCK FORMAT

The TC Codeblock format is a fixed length data entity shown in Figure 3-1. The codeblock is formulated using a systematic coding technique which contains N information bits in the leading octets and the error control in the last octet. The TC Codeblock contains an integer number of octets with a maximum overall length of 8 octets (64 bits).

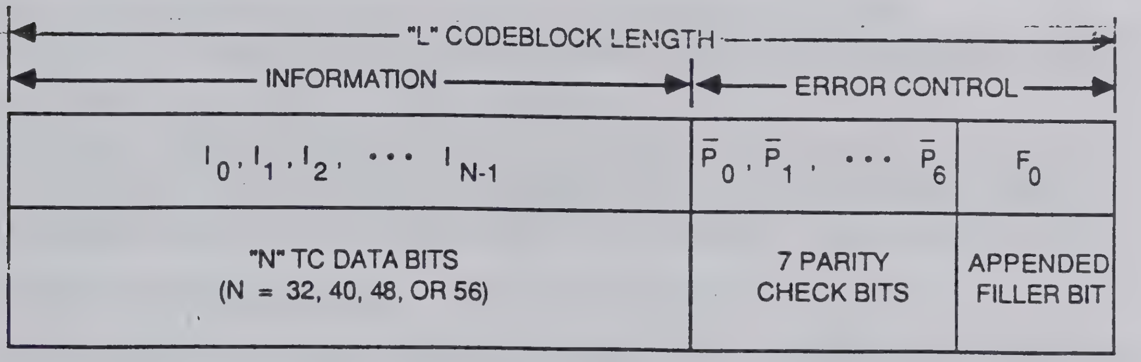

"L" CODEBLOCK LENGTH
INFORMATION
ERROR CONTROL
$I_0, I_1, I_2, \cdots I_{N-1}$
$\bar{P}_0, \bar{P}_1, \cdots \bar{P}_6$
F_0
"N" TC DATA BITS (N = 32, 40, 48, OR 56)
7 PARITY CHECK BITS
APPENDED FILLER BIT

Figure 3-1: Telecommand Codeblock Format

Within any given mission, the overall length "L" of the TC Codeblock shall be fixed and shall be selected from the following standard lengths:

L = 40 bits (N=32)
L = 48 bits (N=40)
L = 56 bits (N=48)
L = 64 bits (N=56)

The preferred length is L = 64 bits.

The COMPLEMENTS of the seven parity check bits, P_0 through P_6, are located in the first seven bits of the last octet of the TC Codeblock. The complements are used to aid in maintaining bit synchronization and detection of bit slippage. The encoding procedure for generating these parity bits is described in Section 3.3.1.

The last bit of the last octet, F_0, is a filler bit appended to provide an overall Codeblock length which is an integer number of octets. This Filler Bit shall always be a "zero".

3.2.2 COMMAND LINK TRANSMISSION UNIT (CLTU) FORMAT

The CLTU is the data structure which carries the TC data as a contiguous series of encoded TC Codeblocks across the Channel Service. The encoded TC data within the CLTU consist of one Input Data Entity from the layer above. The CLTU has the structural components shown in Figure 3-2.

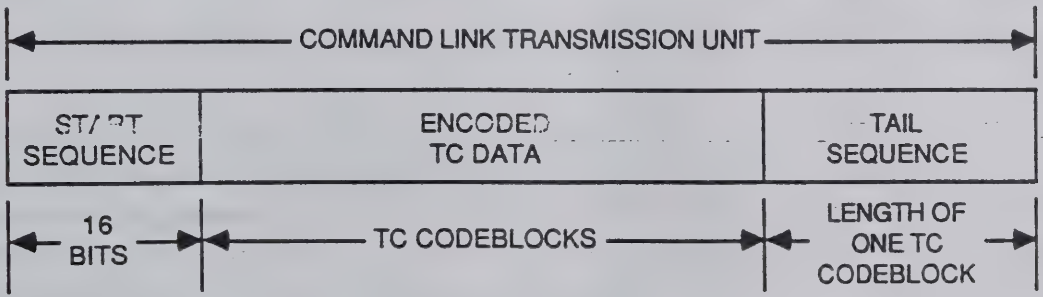


Figure 3-2: Components of the CLTU

3.2.2.1 CLTU Start Sequence. The CLTU Start Sequence field delimits the start of the block coded TC data within the CLTU. It consists of a 16-bit synchronization pattern with low autocorrelation sidelobes and shall have the following pattern:

1 1 1 0 1 0 1 1 1 0 0 1 0 0 0 0

BIT 0 BIT 15

3.2.2.2 Encoded TC Data. The Encoded TC Data field consists of a set of TC Codeblocks which have been encoded in accordance with the TC Codeblock encoding procedure. Fill bits may be added to pack the input data to complete a TC Codeblock. In addition to error control bits, these codeblocks contain the input data to this layer, plus any fill bits that were appended to meet codeblock length constraints.

3.2.2.3 Tail Sequence. The CLTU Tail Sequence field is a data structure which is constructed specifically to be a noncorrectable codeblock which delimits the end of a CLTU by stopping the decoding process. The Tail Sequence shall have the same length as a TC Codeblock and its pattern shall be alternating "ones" and "zeros", beginning with a "zero" and ending with a "one". This pattern differs from the nearest codeblock of the same length by 2 bits.

3.3 STANDARD PROCEDURES WITHIN THE CODING LAYER

The following sections define the TC Codeblock encoding and decoding procedures.

3.3.1 TC CODEBLOCK ENCODING PROCEDURE.

A systematic block coding procedure is used which always generates 7 parity check bits per codeblock and which is always computed from 56 information bits. The parity check bits are then COMPLEMENTED and placed into the codeblock as shown in Figure 3-1.

The code used is a (63,56) modified Bose-Chaudhuri-Hocquenghem (BCH) code which uses the following generator polynomial to produce the seven parity bits:

$$g(x) = x^7 + x^6 + x^2 + x^0$$

It may be desired to shorten the transmitted codeblocks. This is accomplished by reducing the number of TC data bits contained within the transmitted codeblocks. To maintain octet boundaries and reasonable efficiency, 32, 40, and 48 bits are the only shortened TC data field sizes permitted.

4.2.1 TC TRANSFER FRAME FORMAT

The TC Frame (Figure 4-2) contains the following major fields:

Major Field	**Length (Octets)**
FRAME HEADER	5
FRAME DATA FIELD	Variable (up to 1019)
FRAME ERROR CONTROL (Optional)	(2)
	1024 octets (maximum)

The maximum TC Frame length allowed by a particular spacecraft or ground implementation on a particular Virtual Channel may be less than the maximum specified here.

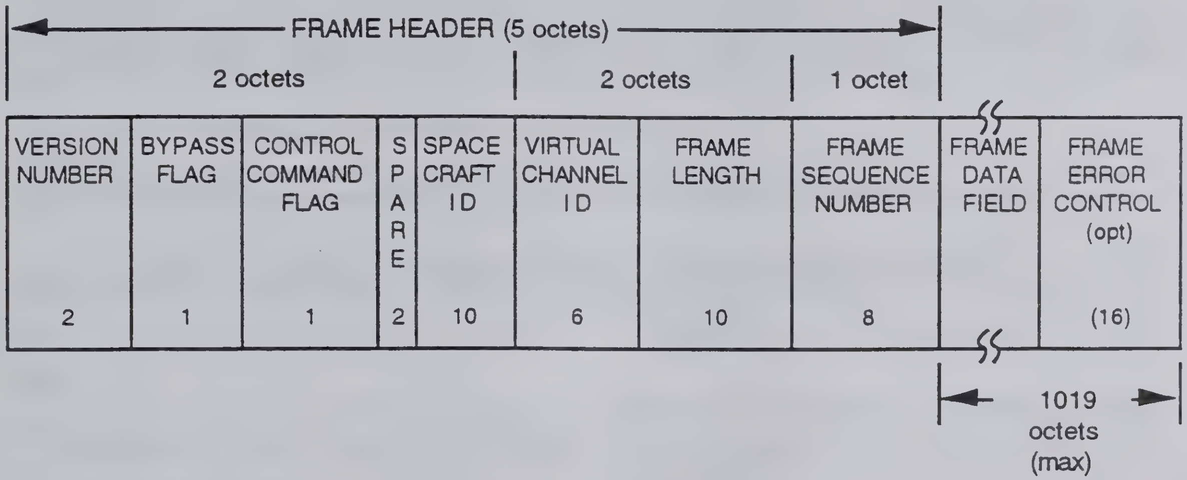


Figure 4-2: TC Transfer Frame Format

4.2.1.1 **Transfer Frame Header.** The FRAME HEADER of the TC Transfer Frame consists of the following fields, grouped into octets as shown:

Field	**#Bits**	**#Octets**
Version Number	2	
Bypass Flag	1	
Control Command Flag	1	
Reserved Spares	2	
Spacecraft ID	10	2
Virtual Channel ID	6	
Frame Length	10	2
Frame Sequence Number	8	1
		5 octets

The format of the TC Segment is shown in Figure 3-2.

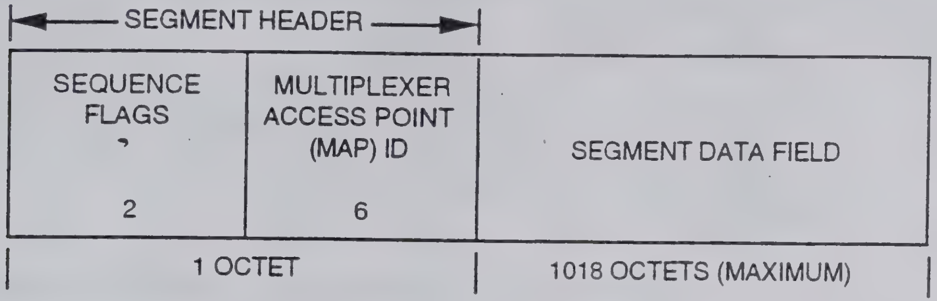


Figure 3-2: Telecommand Segment Format

3.2.2.1 **Segment Header.** The Segment Header contains the following two fields:

(1) Sequence Flags (Bits 0,1)

This two bit field delimits the higher layer TC User Data Unit by indicating the sequential position of the TC Segment relative to the TC User Data Unit (e.g., TC Packet) of which the TC Segment is a part. The flags are interpreted as follows:

Bit 0	Bit 1	Interpretation
0	1	First Segment of TC User Data Unit on one MAP
0	0	Continuing Segment of TC User Data Unit on one MAP
1	0	Last Segment of TC User Data Unit on one MAP
1	1	No segmentation (one TC User Data Unit or multiple complete TC Packets)

(2) Multiplexer Access Point (MAP) Identifier (Bits 2 through 7)

The MAP facility allows user command data from different sources to be multiplexed together so that they share the communications capacity of one Virtual Channel, thus preventing any one user from monopolizing the data transmission resource.

This six-bit field enables up to 64 MAP addresses (from MAP 0 to MAP 63) to be associated with each Virtual Channel provided by the Transfer layer. Different TC User Data Units (e.g., separate TC Packets) arriving at the input to the Segmentation layer are allocated to a MAP. The segmentation and aggregation processes are conducted independently for each MAP. The resulting TC Frame Data Units from up to 64 MAPs are then multiplexed onto one Virtual Channel in accordance with user's delivery priorities and instructions. Certain MAPs may have higher transmission priorities than others.

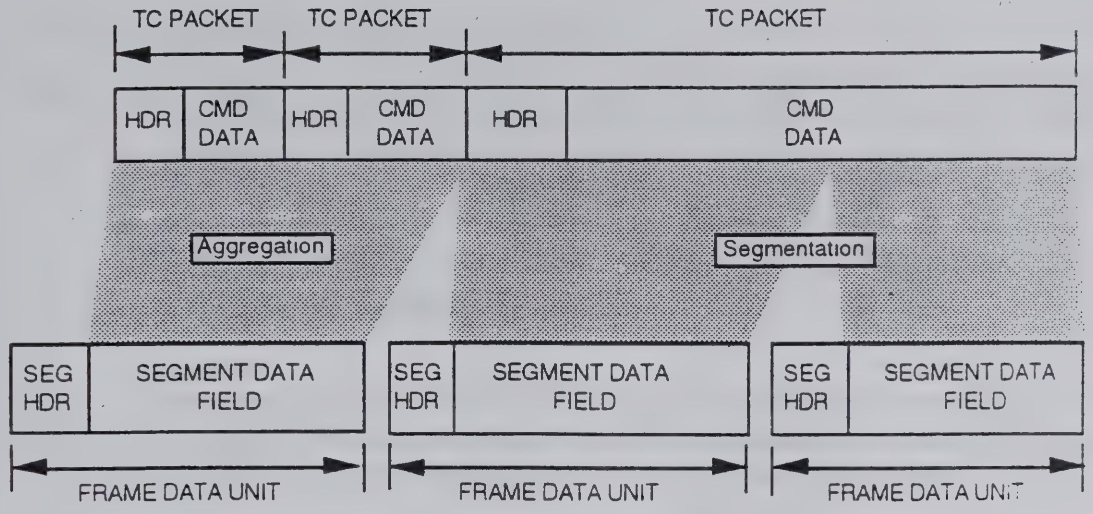


Figure 3-3: Example of the Segmentation Procedure

3.3.2 RECEIVING END SEGMENTATION PROCEDURES

The receiving end of the TC Segmentation layer performs the following processing steps:

(1) Accepts a stream of multiplexed TC Segments/Frame Data Units on one Virtual Channel from the Transfer layer.

(2) Sorts these Segments according to the MAP IDs which appear in their Segment Headers.

(3) a. For TC Frame Data Units containing a segment of a TC User Data Unit: reassembles the Segments (less headers) for each MAP, using the Sequence Flags, in order to recreate the original TC User Data Unit.

b. For all other TC Frame Data Units: extracts the TC Packets or TC User Data Unit, using the Frame and Packet Length fields.

(4) Passes the resulting TC User Data Unit(s) to the layer above.

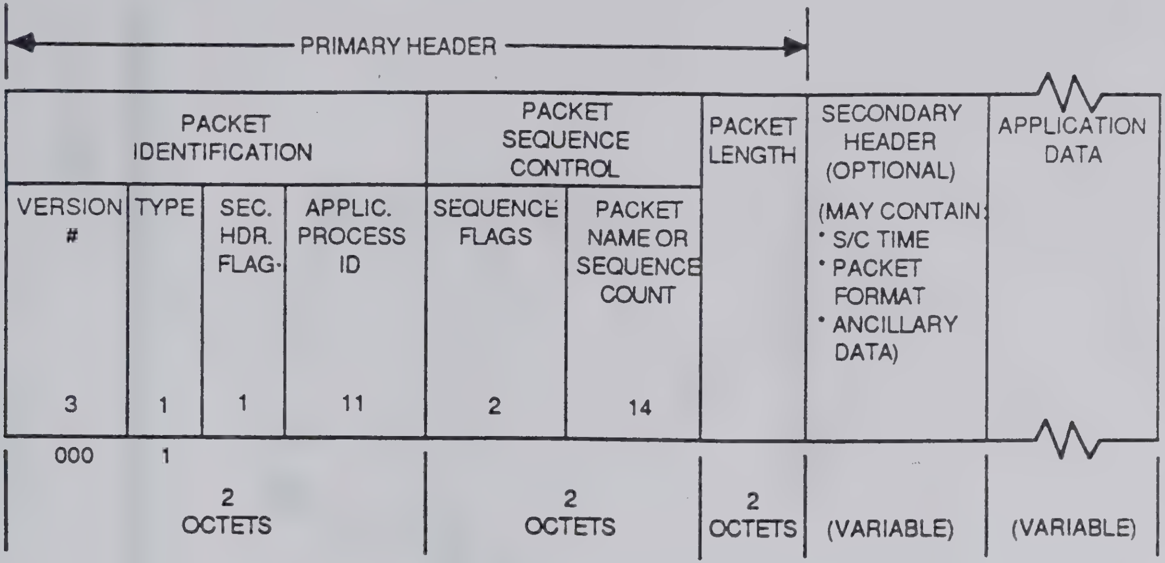


Figure 5-1: Telecommand Packet Format

5.2.1 PRIMARY HEADER

The Primary Header consists of 6 octets subdivided into the following fields:

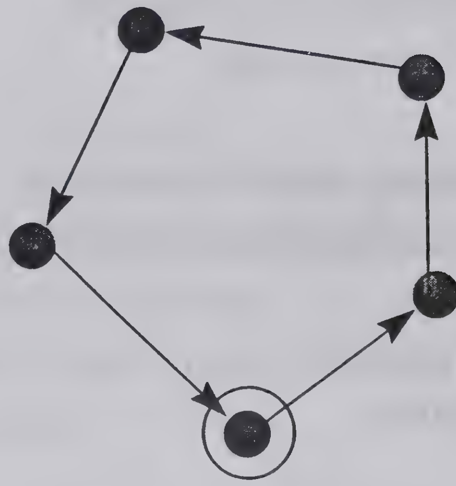
Field		Length (Bits)
PACKET IDENTIFICATION		16
- Version Number	(3)	
- Type	(1)	
- Secondary Header Flag	(1)	
- Application Process ID	(11)	
PACKET SEQUENCE CONTROL		16
- Sequence Flags	(2)	
- Packet Name or Sequence Count	(14)	
PACKET LENGTH		16

	Total =	48 bits (6 octets)

Network Topologies

Logical Token Ring

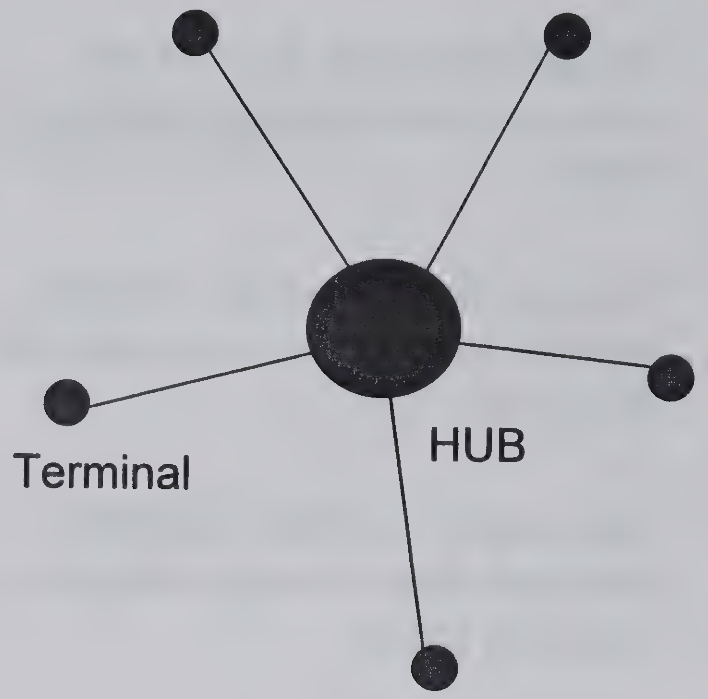
- **Point-to-point protocol**
- **Single user has access to network resources at a given time**
- **Access is shared by passing logical token from one user to the next**
- **Not useful on GEO satellite network due to large delay in passing token**



Token Passing

Star Network

- **Point-to-multipoint connectivity**
- **Many small terminals communicating to central hub**
- **Typically asymmetric data paths**
  - **Low rate, terminal to hub**
  - **High rate hub to terminal**



VSAT

- **Very Small Aperture Terminals**
  - **0.6 to 2.4 m in diameter**
- **Primary application - Large group of remote terminals that send short bursty messages to central location**
- **Typically operate in Ku-band (11-15 GHz)**
- **Operate in star network configuration**
- **Each VSAT terminal has relatively modest data rate performance**

Typical VSAT Users

Banks

Airlines (reservations)

Hotel chains

Fast-food chains

Brokerage firms

Retail store chains

Corporate and institutional networks

Typical VSAT Architecture

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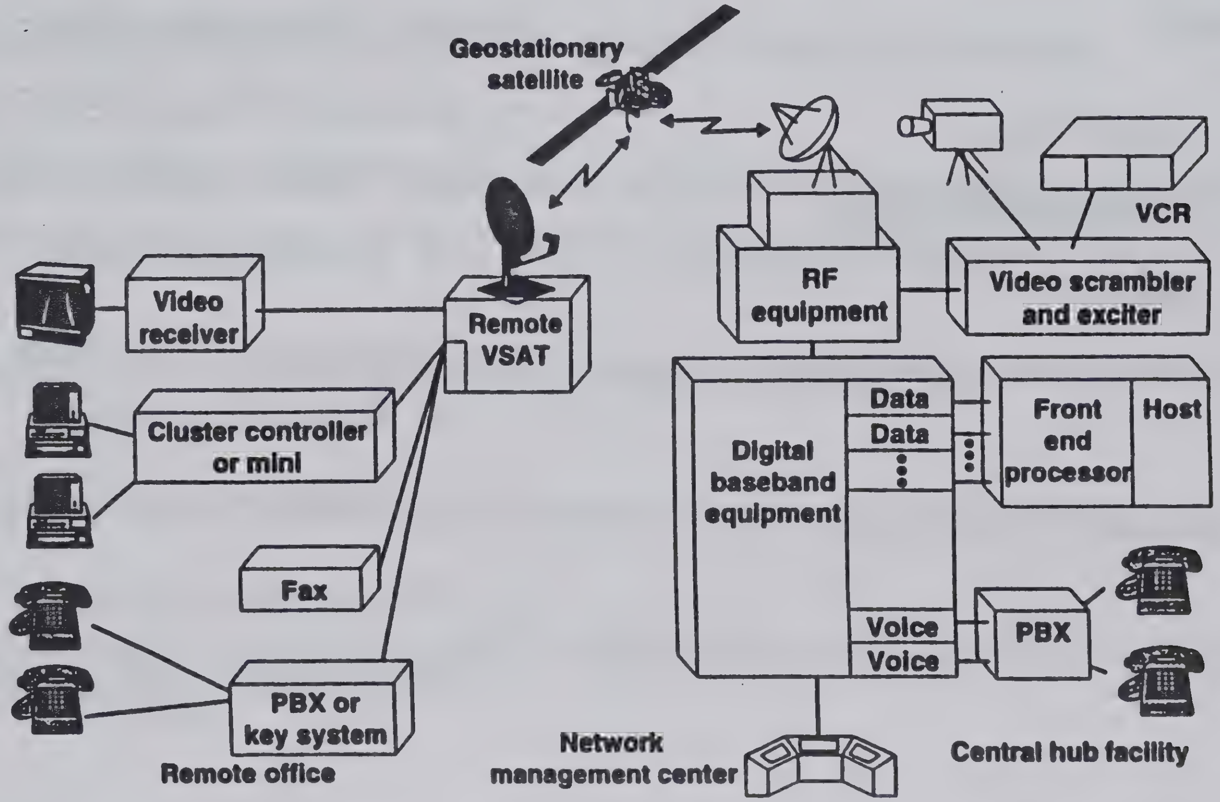

Figure 7.4 Architecture of a typical VSAT star network (courtesy of Hughes Network Systems).

VSAT Characteristics

Services:

- Packet Data
- Compressed Voice
- Fax
- Video teleconference

Signal Characteristics:

- Inbound: from VSAT to Hub
  - 600 b/s to 64 kb/s
  - TDMA with Aloha
- Outbound: from Hub to VSAT
  - 64 kb/s to 512 kb/s
  - TDM format
- FEC commonly used
- ARQ almost universal

Multi-access Protocol Issues

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- **Efficiency - fraction of time useful data is carried**
- **Access delay - time between arrival of message at VSAT terminal and start of successful transmission**
- **Stability - possibility of long term congestion**
- **Robustness - presence of errors and equipment failure**
- **Operation properties - difficulty of start-up and addition of new stations**
- **Cost/Complexity**

Aloha Protocol

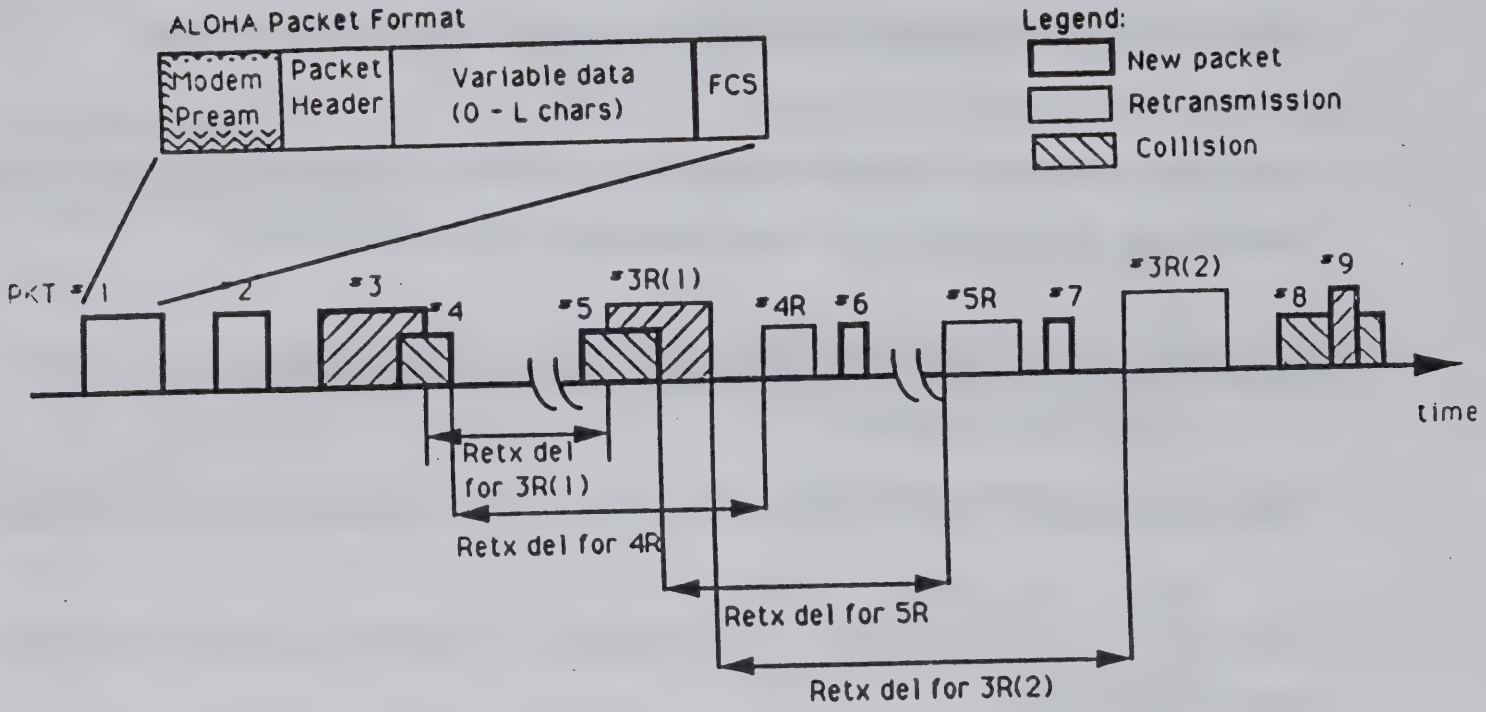
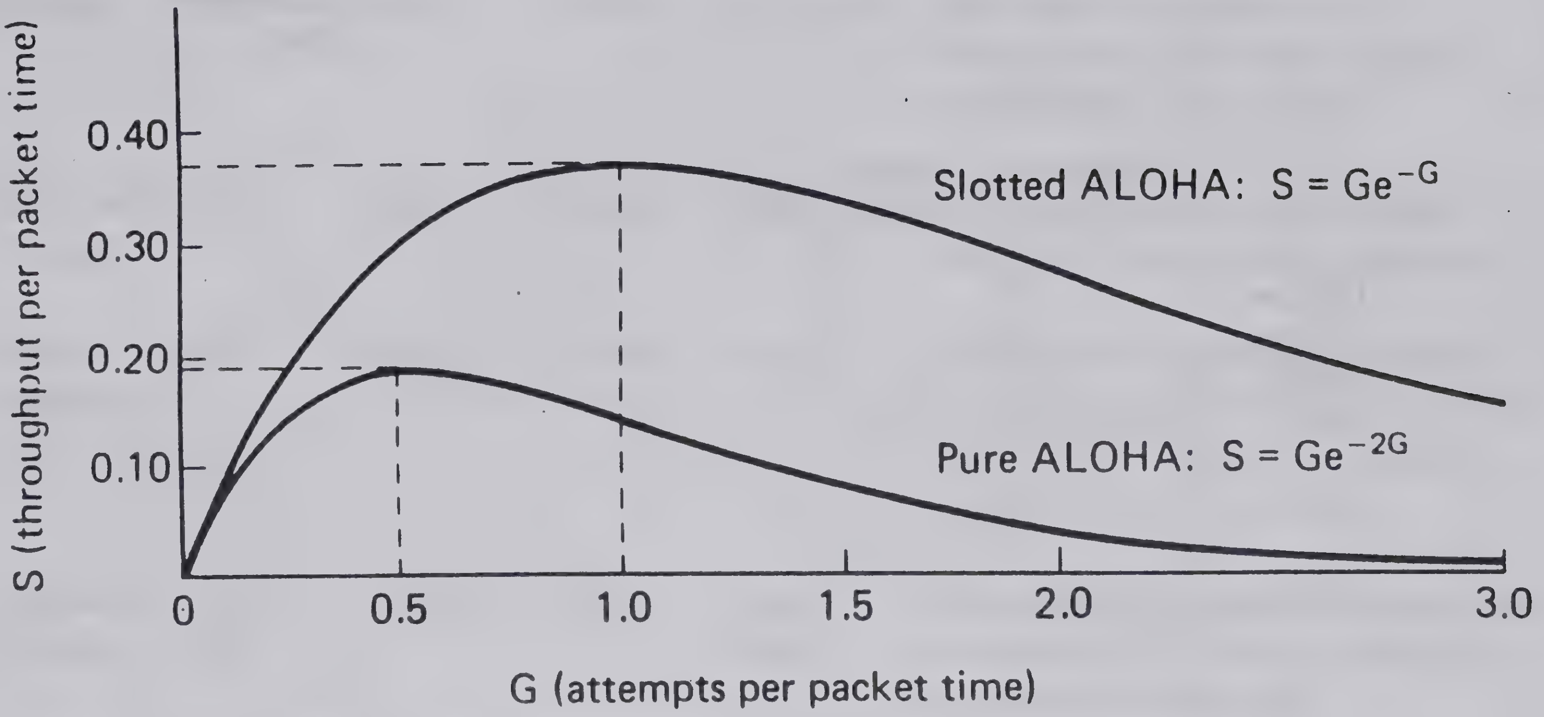
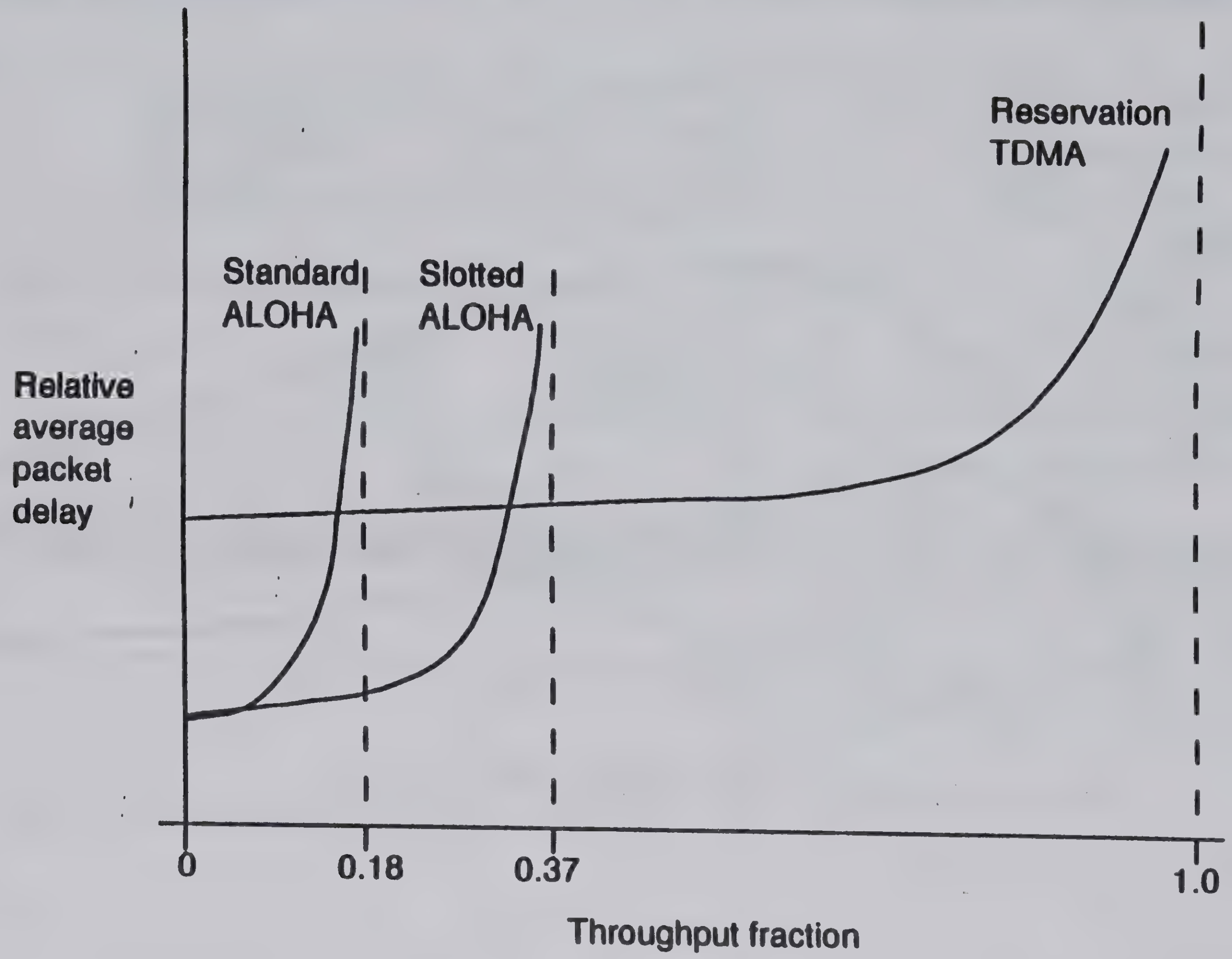


Fig. 7.3 *Illustration of channel events for the ALOHA protocol*

Aloha Throughput Performance



Aloha Delay Performance



Protocol Comparison

Protocol	Capacity	Delay	Robust	Cost	Remarks
Aloha	0.18	Low	Good	V. Low	Simplest at expense of throughput, good for short, variable-length packets
Slotted Aloha	0.37	Low	Good	Med	Simplest slotted technique, good for fixed-length packets
SREJ-Aloha	0.3	Low	Good	Low	Significant capacity increase over Aloha with minimal added complexity, short to medium, variable-length packets
Packet CDMA	0.1 - 0.3	V.Low	Good	Low Med	Low delay and spread spectrum advantages. Complex FEC for high end of capacity
TDMA-DAMA	0.6-0.8	High	Poor	High	High throughput by reservation at expense of delay and complexity. Good for long packets

Direct PC Network

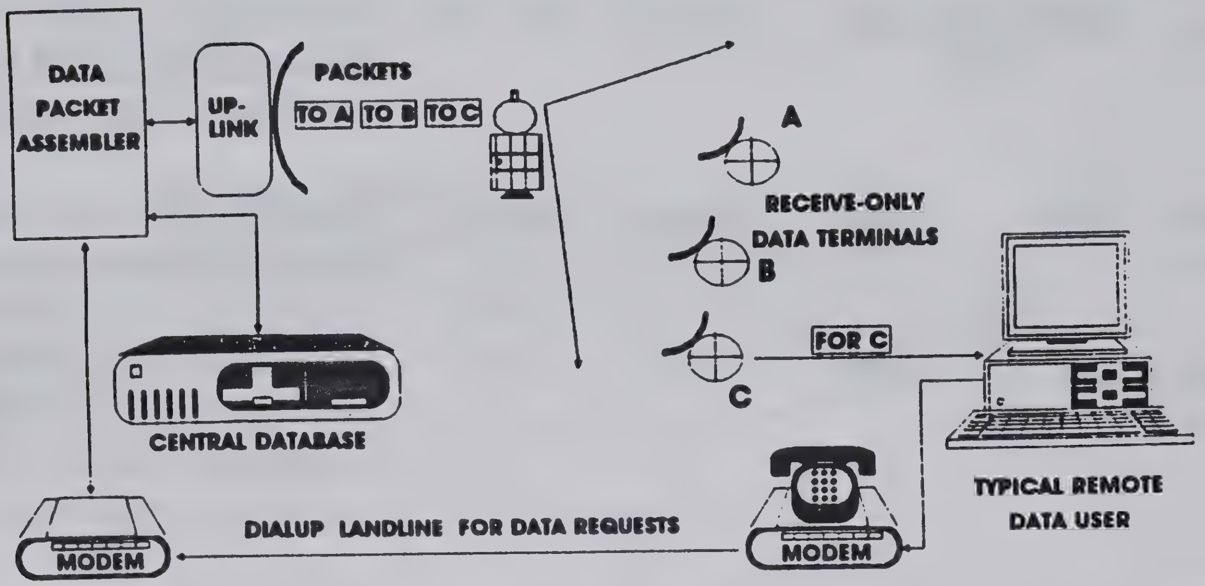


Figure 7.5 Using a data broadcast to integrate the PC into a VSAT data communications network.

Direct PC Applications

Table 7.3
Typical Applications for Integration of the PC With the VSAT, Utilizing Data Broadcasting

Application	*Example*	*Availability*
Data broadcasting	Stock market ticker; commodity markets	Existing in U.S. and other major economies
	Wire services and electronic newspapers	Dow Jones, Reuters, and others available
	Airline flight schedules, arrivals, and departures	Used privately by airlines; available to the public over wire networks
	Traffic information	In some large cities over radio towers
Interactivity through PSTN	E-mail	Private networks
	World Wide Web access	An ideal application
	File transfer	Private networks
	Download of computer games	Developing application

Direct PC Equipment

Table 7.4
Specifications of the DirecPC Equipment to be Installed at the User Site

Element	*Feature*	*Characteristic*
Receive antenna	Diameter	60 cm (24 inches)
	Frequency range	11.7 to 12.2 GHz
	Polarization	Linear
	Cable connection	Single RG6/U coax
PC internal card	Type	ISA bus card, 16-bit ISA standard
	Bit rate	11.79 Mbps
	Input frequency range from antenna cable	950 to 1450 MHz
	Security	DES-based conditional access
Software	Operating system	MS-Windows 3.1 or Windows 95
	Software packages	Antenna pointing utility Package Explorer Turbo Internet Device Driver Digital Package Delivery
PC hardware requirement	Type	IBM-compatible
	Processor	Intel 486/66 MHz
	Configuration	Multimedia

Network Summary

- **Network Topologies**
  - **Mesh network**
  - **Logical Token-ring network**
  - **Star network**
    - **– VSAT**
      - **Large group of remote terminals that send short bursty messages to central location**
      - **Aloha and TDM protocols commonly used**
    - **– DirectPC**
      - **Combined satellite and terestrial network**
      - **Best for broadcast information**